PLANNING FOR WATER SCARCITY: THE VULNERABILITY OF THE LAGUNA REGION, MEXICO

A Dissertation

by

MARIA DEL ROSARIO SANCHEZ FLORES

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2009

Major Subject: Water Management and Hydrological Science

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Approved by:

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ABSTRACT

Planning for Water Scarcity: The Vulnerability
of the Laguna Region, Mexico.
(August 2009)
Maria del Rosario Sanchez Flores, B.S., Monterrey Tech.;
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Co-Chairs of Advisory Committee: Dr. Ronald A. Kaiser
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This dissertation examined declining groundwater availability and management strategies for addressing water shortages in the Laguna region located in the states of Coahuila and Durango. Excessive pumping of groundwater in the Laguna region has resulted in a dramatic decline in the water level of the aquifer and in the region's water supply. Since agriculture has been highly dependent on groundwater, this may lead dramatic changes in the agricultural sector of the regional economy. This research was an exploratory investigation of water users' beliefs and of options regarding water scarcity that could help design a stakeholder framework for planning the region's water resources. To address this problem, a combination of quantitative and qualitative techniques were used. A systems theory simulation model was used to measure the economic vulnerability of the main agricultural products at different scenarios of water volume in the aquifer. Grounded theory methodology was used to address water users' beliefs concerning water conditions and planning strategies. Preference and feasibility analysis was used to identify the most preferable planning strategies among water stakeholders. Statistical analyses were used to support the results of the quantitative assessments.

The results of the simulation model showed a significant impact on economic production given different scenarios of water volume and of higher probabilities of droughts. From the qualitative assessment four main findings were identified: lack of

localized data, cognitive communication dissonance, disagreement on problem identification and disagreement on possible solutions. From the preference and feasibility analysis, the most favored strategies were: more comprehensive research, conservation campaigns, education and investment for water efficiency techniques. The lowest values were gained by privatization, new drillings, decentralization, construction of new dams, and the continuation of the actual pumping condition. Results showed there was no preference for dramatic changes in the actual model of water use. The vulnerability of the region was not shown to be equal among users; it was higher for communal users and cities, and lesser for private farmers and industries. The potential for sustainability was not high enough to expect a significant change in the near future in the water planning process.

DEDICATION

I wish to dedicate this work to my sister Gaby and to her children, Emilito, Barbara and Eduardo, who have been in each thought, word and blank space of this writing. They have been my inspiration, strength and willingness for the fulfillment of this new achievement. I know they will continue to accompany me in the new journeys to come. For good and bad, for science and love, always in my heart.

ACKNOWLEDGEMENTS

I would like to thank from the deep bottom of my heart my committee co-chairs, Dr. Kaiser and Dr. Giardino for their unconditional support, friendship and guidance throughout this research and for all the experiences we have shared since I arrived in College Station. I am grateful for having them as my advisors and as my friends. I also want to thank my committee members, Dr. Jacob and Dr. Brumbelow for their invaluable knowledge, support, guidance and attention to make this work an outstanding one. I will always remember what I learned thanks to them.

Thanks also go to my friends and colleagues, especially to Prakash, Bahvna and Mali who I will take along in my heart and in my scientific reasoning. Special thanks go also to Dr. Val Silvy, for being much more than our program coordinator, and for the unique and special human being she has been to all of her students.

I am especially grateful to Dr. Gabriel Carranza for his trust, confidence and for introducing me to the great opportunity of being part of the Texas A&M community.

I also want to thank the Coahuila State Government, especially to Governor Humberto Moreira for his commitment to education, research and for helping me with the fulfillment of this new achievement.

And last but not least, thanks to my parents for their endless support, trust and love and to God for keeping them close to me.

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I. INTRODUCTION

Worldwide, water availability is a growing problem. The United Nations, in collaboration with the World Health Organization (WHO), monitor access to water and their statistics are sobering. According to the World Health Organization, an estimated 1.1 billion people worldwide currently lack access to an adequate supply of fresh potable water (WHO, 2000). The United Nations predictions for 2025 indicate that 3 billion people shall be under a water stress situation (UNDP Report, 2006). Throughout the world, the twin problems of decreasing water availability and declining water quality threaten human and environmental health and imperil economic development. Groundwater mining occurs when extraction exceeds recharge and this pattern is accelerating, and unsustainable groundwater use occurs on every continent except Antarctica. While most of the optimal large scale reservoirs sites are developed, new reservoirs are still contemplated, but are constrained by environmental concerns and limited funding.

Water availability and solutions to declining availability vary greatly from region to region and country to country. In Latin American, which contains an estimated 35% of the world's freshwater resources, it is predicted that 70% of the population will not have access to water by 2025 (UNDP Report, 2006). Statistics on Mexico are equally revealing and daunting. Nationwide, agriculture accounts for nearly 80% of Mexico's total annual use, cities about 17% and industry about 3%. Surface water provides about 65% and aquifers about 35% of the total water used (CNA, 2008).

This dissertation follows the style of the American Water Resources Association.

These national statistics are deceiving as there are imbalances between water demand and sources of supply. Water resources are abundant in the sparsely populated south and increase in scarcity in the center and north of the country. Due to population growth and internal migration toward the arid and semi-arid central and north part of the country, many water resources in these regions are overexploited. Nearly 80% of Mexico's population lives in the center and north of the country which account for 80% of GDP, over 90% of irrigated land and 75% of industrial activity, yet these regions only have 32% of the country's renewable water resources (CNA, 2006). These areas are facing acute water shortages that include the overexploitation of 101 of its 653 aquifers (CNA, 2008). Most of these are in the central and northern portions of the country.

In response to these impending shortages, the federal government enacted the Ley Nacional de Agua in 1992 restricting the awarding of new pumping permits in aquifers where extraction exceeded recharge. The law was amended in 2004 to encourage more regional involvement in water management and to encourage water marketing in aquifers where mining was taking place. New water users in these aquifers could no longer received a new pumping permit but had to acquire a permit from an existing user. Implementation of this law is ongoing and not complete.

This dissertation examines declining groundwater availability and management strategies for addressing water shortages in the Laguna region located in the states of Coahuila and Durango (Figure 1.1). This is one of the regions experiencing an overexploitation of its aquifers. The region has an average annual temperature of 68 ° F (20 °C), a mean annual rainfall of 9 inches (253 mm) and a mean evaporation rate of 98 inches (2,500 mm). Surface water resources are limited which requires agriculture, municipalities and industries to rely on groundwater. The situation is projected to become economically acute by the year 2025 (CNA, 2004). Figure 1.1 shows the hydrological basin and the location of the Laguna Region.

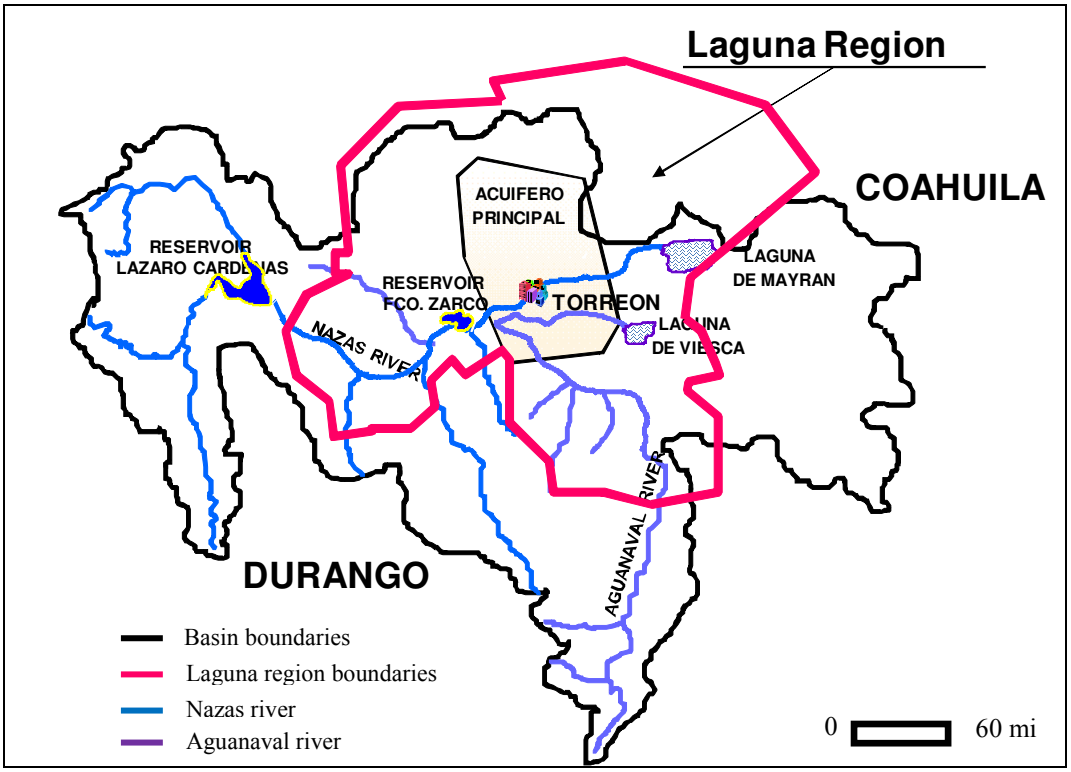


Figure 1.1 Hydrological Basin and Location of the Laguna Region. (CNA, Cuencas Centrales del Norte, 2005).

PROBLEM STATEMENT

Excessive pumping of groundwater in the Laguna region is resulting in a dramatic decline in the water level of the aquifer and in the region's water supply. Since agriculture is highly dependent on groundwater, this will lead dramatic changes in the agricultural sector of the regional economy. This research is an exploratory investigation of water users' beliefs regarding water scarcity and of options for addressing scarcity that could help design a stakeholder framework for planning and management of the region's water resources.

Traditional planning and management approaches and reliance reservoirs, transfers and tapping groundwater continue to dominate, but new methods focusing on efficiency improvements, conservation, demand management and reallocation of water among users are being considered. The shift to these new approaches is not universally

accepted and they may not offer permanent solutions to reducing the gap between increasing demands and limited supplies. The traditional centralized water planning and management paradigm of dam building and increased aquifer pumping while still entrenched in national water planning is under greater stress. Among the factors driving questions of the adequacy of centralized planning are high construction cost, limited new supplies, imperatives for greater efficiency through conservation, and increased stakeholder involvement in decision-making. The growing questions to major water projects have led funding organizations to consider integrated approaches to water planning. The World Bank has adopted a funding policy requiring the adoption of a comprehensive planning framework emphasizing "decentralized management and delivery systems and fuller participation by stakeholders". This framework guides water development and management decisions in regions where significant problems exist concerning water scarcity, efficiency of service, and the allocation of water among competing and conflicting uses (World Bank, 1993). These conditions exist in the Laguna region.

RESEARCH OBJECTIVES

The objectives of this exploratory research include:

1. Ascertaining water user understanding of the short and long term consequences of groundwater mining including user acceptability of data accuracy and satisfaction with the planning process.
2. Identification of user preference for an array of management options for addressing declining water availability.
3. Development of a quantitative model, based on the systems theory approach (Stella software) to evaluate the economic impact given different scenarios of groundwater availability.
4. Offer recommendations of what planning policies could be applied more successfully in the Laguna region given the results.

The focus will be on developing a theory of planning under a vulnerable water-scarce condition. The presentation approach will be different from the traditional

dissertation, as separate papers of publishable quality will constitute the dissertation. The research for these papers will focus on planning under a water-scarce condition based on different lessons and planning strategies around the world, and specifically in the Laguna region. The approach will cover water-scarce planning policies from a contextual perspective identifying hydrological science-policy issues, and at the same time, will assess water scarcity from a user's perspective, allowing for different categories of water and values. It is important to identify water-scarcity issues as a two-way road: the scarcity of water resources itself, and the perception of water scarcity on different users.

This approach will add value to the political-institutional framework addressed in the following sections, to evaluate success or failure of planning strategies under a water-scarce condition. At the same time, and using both qualitative and quantitative approaches, a modeling assessment will be developed to simulate and measure the vulnerability of the Laguna region, drawing on actual economical, political and social regional conditions to evaluate possibilities for a successful water-scarce planning assessment.

A great challenge in this research was the integration of a comprehensive approach to the main issues regarding planning assessment under a water-scarcity condition, both through a qualitative and quantitative vulnerability analysis of the Laguna region. However, the qualitative approach model fills the gaps in the quantitative approach and offers not only new alternatives and key elements for future planning assessments and research trends, but also new variables that can be easily overlooked by a soley quantitative approach. As Pilkey and Pilkey-Jarvis (2008) recommend: "Qualitative models (what if) are expected to produce answers accurate enough to be useful for a wide range of societal purposes, magnitudes and mechanisms". However, caution was applied considering model limitations and boundaries regarding the subjectivity that might apply during the analysis of the results.

This dissertation is divided into five different sections. Section II outlines the parameters of the problem, summarizes the planning literature and outlines methods used to collect and analyze the data. A systems approach outlining the economic

consequences of four different scenarios of water availability and higher probabilities of drought conditions based on Stella modeling software are presented in Section III. Water user beliefs and needs related aquifer sustainability based on grounded theory methodology are outlined in Section IV. Preference and feasibility analysis of thirty-five alternatives listed according to the interviewees responses and to the literature reviewed are presented in Section V. The alternatives that gained the higher values of preference and feasibility tend to be partially sustainable or limited and with a short-term perspective. This means that the actual condition only offers a limited variety of options for decision-making.

With these assessments, vulnerability is also tightened to specific conditions and perspectives, offering new insights on how water scarcity threats can be more successfully addressed and crisis management processes can be better managed. Results obtained from these analyses point out a limited potential for sustainability in the region, but also an interesting area of opportunity for future research. Section VI outlines research conclusions, study limitations and offers recommendations for future research and action.

II. RESEARCH SETTING, LITERATURE REVIEW AND METHODOLOGY

The Laguna region faces a number of water challenges including infrastructure replacement, water quality, and limited opportunities for new supply development. Perhaps most critical is the depletion of the aquifer that is the primary water source for cities and agriculture. Before outlining the aquifer depletion issues it will be helpful to describe the regional setting for this issue.

RESEARCH SETTING

Study Area

The Laguna region is a semiarid area located in the northeastern part of Mexico, between the meridians 102°22' and 104°47' West longitude, and parallels 24° 21' and 26° 23' North latitude. It has a mean elevation of 1, 139 meters above sea level and the mountains of Durango and Zacatecas where the recharge areas are located. The region is located in the closed Nazas and Aguanaval river basins and it covers two states (Coahuila and Durango) with fifteen cities (10 from Durango and five from Coahuila) with a total area of 4.79 millions of hectares (Garcia and Guzman, 2007). Figure 2.1 shows the boundaries of the Nazas-Aguanaval basin.

Almost 92% of the land in the region is used for grazing or forestry activities and 4.7% is used for agriculture (García and Guzman, 2007). Figure 2.2 illustrates the boundaries of the main aquifer in the region (Acuifero Principal) along with the main urban centers, the surrounding mountains and the areas of the Mayran and Viesca lagoons.

Figure 2.1 Nazas-Aguanaval River Basin. (CNA-SIGA, 2009).

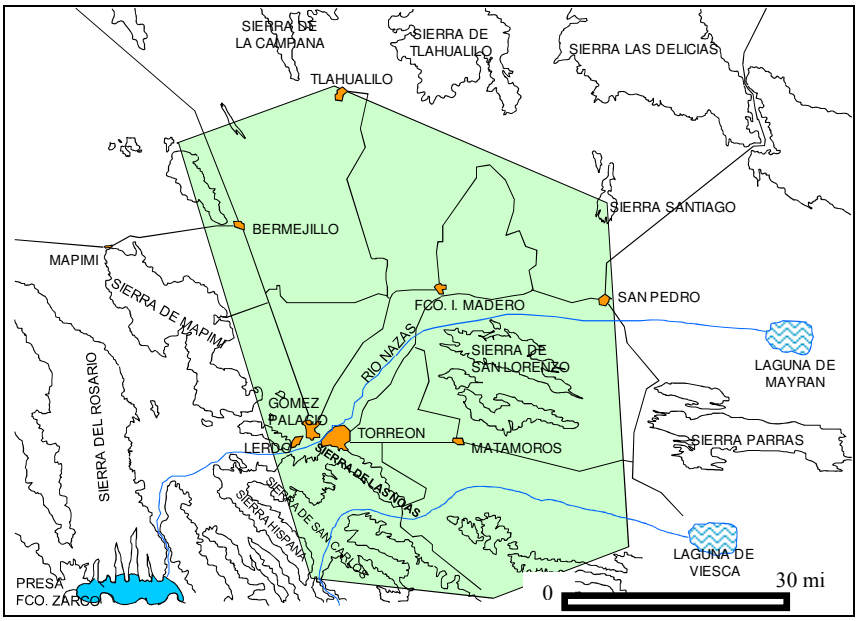


Figure 2.2 Boundaries of the Acuifero Principal in the Laguna Region. Surrounding mountains and main urban centers are also shown (CNA, Cuencas Centrales del Norte, 2005).

The topography of the region is plane with smooth gradients that vary from 0.2 and 1.0 meters per kilometer. The subsurface geology is integrated by alluvial, fluvial and lacustrine sediments. The granular and sand sediments of the Laguna valley constitute most of the material transported by the rivers Nazas and Aguanaval (CNA, 2002).

Climate

The Laguna region is a closed basin located at the southern edge of the Chihuahua desert where evaporation rates exceed precipitation in the order of magnitude 10/1. Mean annual evaporation rates for the region are 2,500 mm with a mean precipitation of 250 mm, resulting in an arid environment. The Durango and Zacatecas mountains to the west and Sierra Madre to the east block the moisture from the Pacific and the Gulf of Mexico respectively resulting in temperature and precipitation seasonality. Summer temperatures are hot averaging 25 C in July; winter in contrast is cool and moist with January temperatures averaging 15 C. The mean annual temperature for the region is 20 C. Given that climate data is collected either for national or state purposes, and considering that the region is distributed equally among two states, Figure 2.3 shows the mean average temperature for the Laguna region that was registered during 2008 as an aggregate average of both states (Coahuila and Durango).

Rainfall occurs mostly in the fall, winter and spring months and it generally falls as a fine drizzle. Strong summer storms, though infrequent, often result in high rainfall and flooding. These rainfall patterns contribute to the seasonal relative humidity in the region where in the fall and winter it averages about 50% whereas in the summer it is 15%. Precipitation variability patterns exist between the mountains to the west and the basin plain to the east. Rainfall is generally greater in the mountains contributing to runoff in the Nazas and Aguanaval watersheds and rivers that flow to the basin plain east of Torreon. Figure 2.4 presents the mean monthly precipitation for the states of Coahuila and Durango. Even though the region registers a mean annual precipitation of 250 mm, the ranges of precipitation variability among the two states are important to highlight. For Coahuila, the mean annual rainfall is 326 mm, and for Durango, the variability

increases up to 499 mm (CNA, 2008). As is shown in Figure 2.4, the variability of rainfall is more acute during July and September.

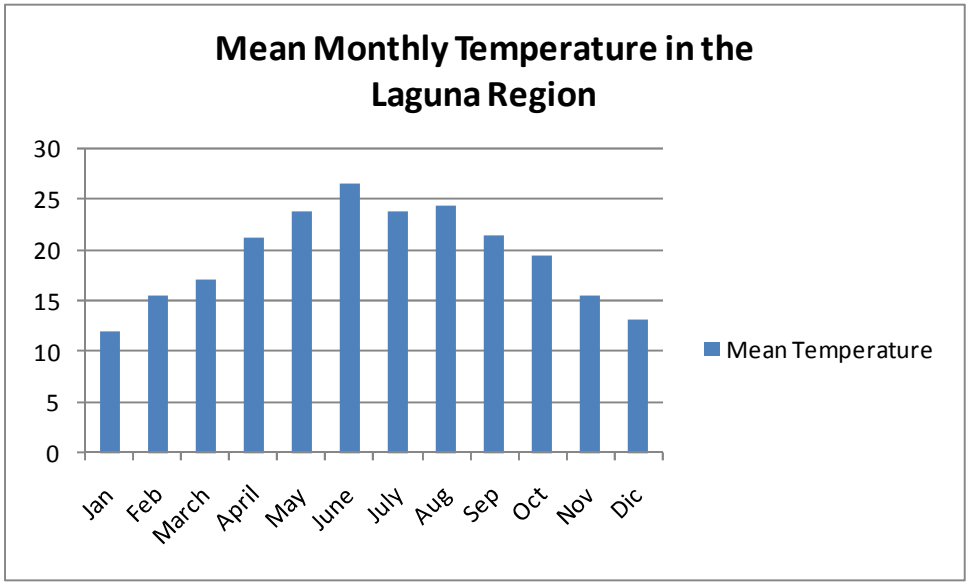


Figure 2.3 Mean Monthly Temperature in the Laguna Region. As an average of registered mean temperatures in the States of Coahuila and Durango (CNA, 2008).

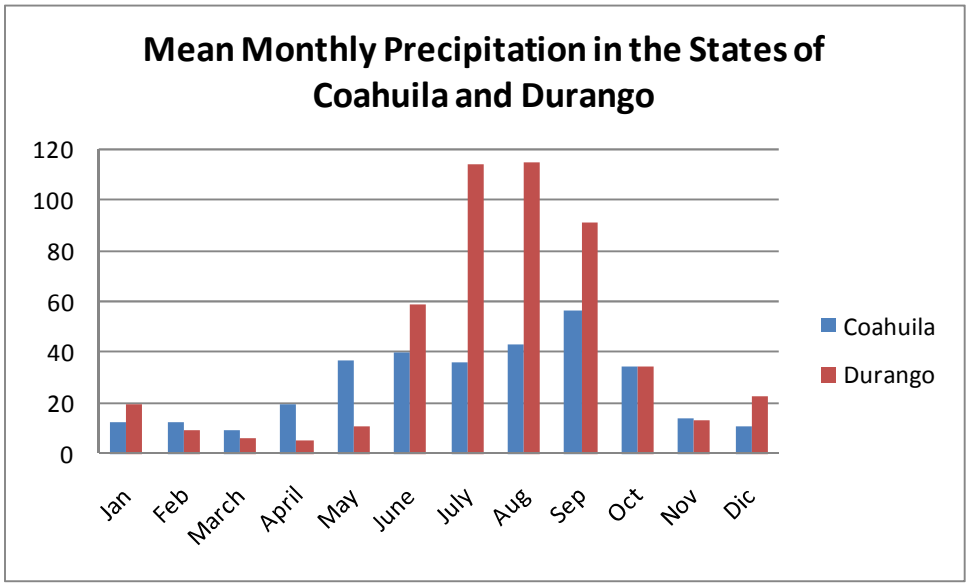


Figure 2.4 Mean Monthly Precipitation in the States of Coahuila and Durango. (CNA, 2008).

Water Resources

The Nazas and Aguanaval watersheds provide the major surface water supplies and the eight aquifers provide groundwater for the Laguna region, with the Acuifero Principal providing 85% of all groundwater use in the region. The Nazas River starts in the mountains of Durango and flows eastward, forming the border between the city of Gomez Palacio in Durango and Torreon in Coahuila. Its watershed, encompassing some 71, 906 km2 of land, is located in and shared by the States of Coahuila and Durango. It has a length of 560 km (about 250 miles) and discharges into desert plain east of Torreon. Two major reservoirs: the Francisco Zarco (436 cubic million meters of storage) and Lazaro Cardenas (3,336 million cubic meters of storage, both located in Durango, capture most of the flow (see Figure 2.5). Downstream of these two reservoirs the river fills smaller water bodies like the Palmito dam (in Torreon, Coahuila) and the Santiaguillo lagoons. The Aguanaval River, which has an average flow of 600 cubic meters per second, is formed from the fusion of the Saín Alto River and Trujillo River in Zacatecas. It receives the flows of the Reyes, Santiago and Mazamitote creeks.

There are other important hydrologic components in the Comarca Lagunera region. The Benjamín Ortega Cantero dam in the municipio of Mapimí, the Francisco González de la Vega dam in Rodeo, the Los Naranjos dam in Simón Bolívar and the Cinco de Mayo dam in San Pedro del Gallo. Also, the Mayran and Viesca lagoons are big natural dams that constitute dry beds at the moment, and are unable to be filled due to the dams located in the Nazas River for the Mayrán lagoon and the city of Matamoros being in the Aguanaval River's flood path.

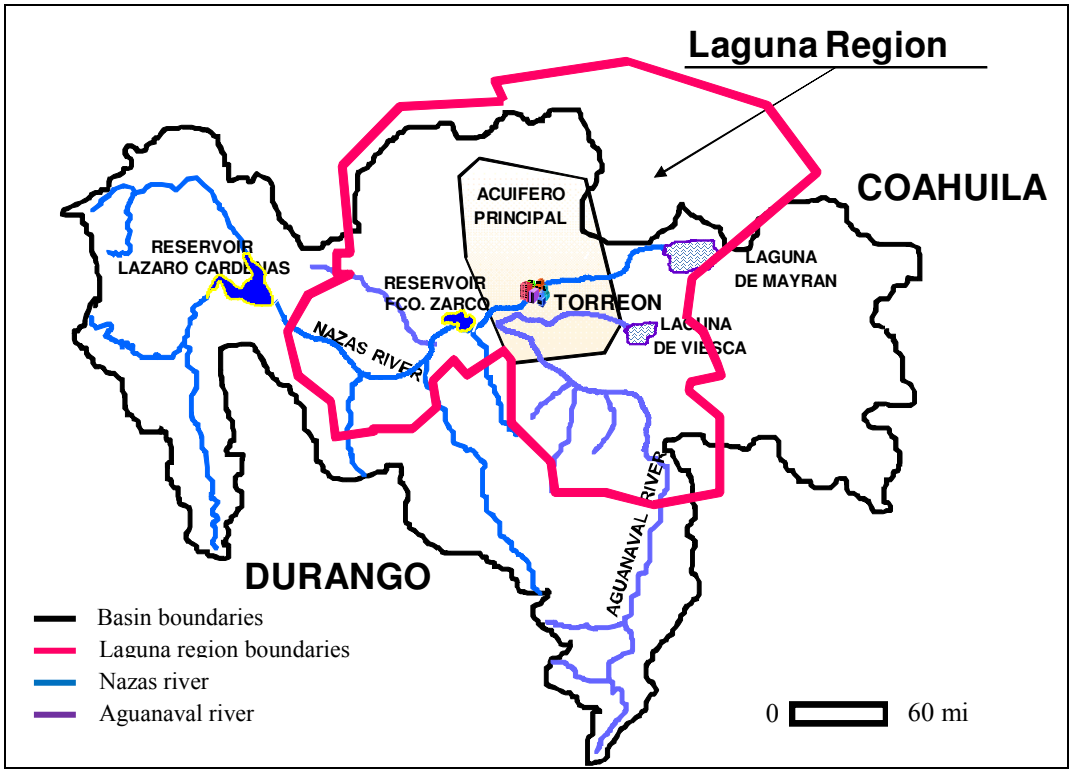


Figure 2.5 Hydrological Basin of the Laguna Region. (CNA, Cuencas Centrales del Norte, 2005).

There are 8 aquifers in the Laguna region, half of which are considered to be overexploited. Figure 2.6 shows the location of the aquifers (in blue) along with the location of the 15 cities in the region and the rates of recharge and extraction for 2005 (CNA, 2005). As is shown, the Acuifero Principal is the main groundwater source in the region, followed by Villa Juarez and Ceballos aquifers that are considered low quality sources. The remaining five aquifers (Aguanaval, Vicente S, Nazas, Acatita and Delicias), supply a very small amount, given their low storage capacity (See Table 2.1).

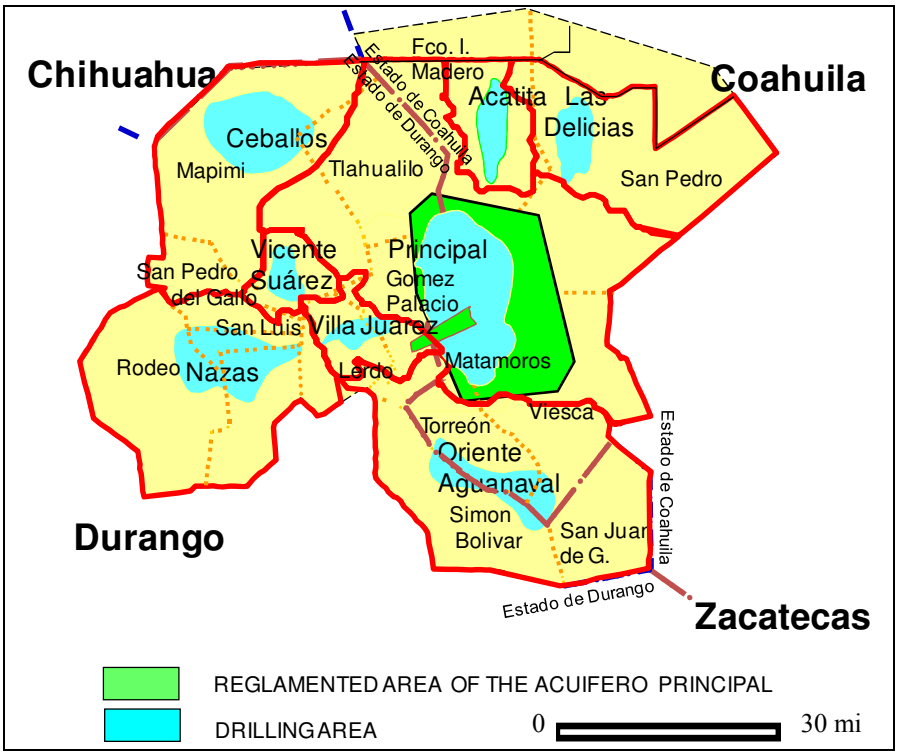


Figure 2.6 Aquifers in the Laguna Region. (CNA, Cuencas Centrales del Norte, 2005).

Table 2.1 Characteristics of the Aquifers in the Laguna Region, 2002. (Cruz and Levine, 1994).
* Data of the Acuifero Principal was updater with data of CNA (2002).

	Principal*	Villa Juarez	Ceballos	Aguanaval	Nazas	Vicente S	Acatita	Delicias	Total
Area (Km2)	14000	600	1826	4000	600	500	648	1800	23974
Extraction rate (Mm^3)	1221	111	103	36	33	13	6	11	1534
Recharge rate (Mm^3)	518	110	48	50	50	10	20	30	836
Rain Average (mm)	260	251	174	262	196	130	254	198	1725
Number of wells	1958	360	246	124	208	54	28	29	3007
Salinity	Low salinity	High nitrates	High salinity	High Salinity					

Of the total groundwater use in the region, 85% is supplied by the Acuifero Principal which has deserved the main focus of federal research in the northeastern part of the country (see Figure 2.6 for aquifers location). According to official numbers, pumping levels show a deficit of around 600 Mm^3 per year, a reduction of the water table from 30 to 120 meters and an average annual reduction of 1.8 to 3 meters (CNA, 2002). Besides the estimations of groundwater depletion for the next 20 to 45 years, the issues concerning water quality have made those predictions even narrower. According to the federal government's water quality study of 1983, the geologic characteristics of the zone and the chemical components of the aquifer morphology demonstrated that 39% of the groundwater is not recommendable for potable uses; 26% is low quality water; and, only 35% is considered high quality water (CNA, 2002, 2004).

Population and Economy

The population of the region is approximately 1,310,000 inhabitants distributed unevenly among the 15 cities and it shows a population growth of 0.4%. Even though population growth might not seem to represent a problem in the near future, it is important to mention that 85% of the population is concentrated in three cities: Torreon, Gomez Palacio and Lerdo (INEGI, 2003; CNA, 2002, 2004; SEMARNAT, 2003). Challenges related to population concentration and infrastructure development are of high importance to city managers. Table 2.2 shows the urban and rural population distribution among the 15 cities.

Table 2.2 Population Distribution in the Laguna Region, 2003. (Thousands of inhabitants) (Garcia and Guzman, 2007).

City	Urban	Rural	Total
Durango	*345*	156	500
Simon Bolivar	0	8	8
Gomez Palacio	**233**	**68**	**300**
Lerdo	**86**	**38**	**124**
Mapimi	13	7	20
Nazas	3	9	12
Rodeo	3	8	11
San Juan de Gpe	0	6	6
San Luis Cordero	0	2	2
San Pedro del Gallo	0	2	2
Tlahualilo	7	9	16
Coahuila	*685*	124	809
Fco. I Madero	27	18	45
Matamoros	58	34	91
San Pedro	50	38	89
Torreon	**547**	**20**	**566**
Viesca	3	15	18
Laguna Region	**1030**	**280**	**1310**

Manufacturing and agriculture are the predominant sectors of the regional economy. Over the last three decades, the *maquila* industry of exportation has developed an important growth, primarily on two sectors: textile and agro industry production. These sectors, along with the mining industry, represent the major economic wealth of the region. Today, there are 15 manufacturing parks that concentrate around 880 industries that are located mainly in the cities of Torreon and Gomez Palacio. From 2000

to 2004, the total value of the mining industry represented 11.6% of the total mining sector National Gross Product (GNP) (Garcia and Guzman, 2007). Agriculture, the main raw material for the agro industry, is a major part of the Laguna economy. The region ranks first place in national production of bovine (20%), goat milk (50%) and forage sorghum (51%), and it participates with the 26%, 16% and 21% of national production of cantaloupe, alfalfa and bovine milk, respectively. It is the most important meat producer in the north-eastern part of the country with an 11% of annual growth rate in agriculture and 20% in cattle industries (Garcia and Guzman, 2007; SAGARPA-INIFAP, 2007).

Water Uses and Users

Total water use in the region is 2,665 Mm^3, of which 91% is used for agriculture, 5.5% for urban-domestic use, 1.4% for industrial use, and 1.3% for cattle production. Of the total water used in the region, groundwater supplies 51% of agriculture, 97% of urban-domestic, and 98% of industrial use and 100% of cattle use. The remaining percentages are covered by surface water (SEMARNAT-CNA, 2004; CNA, 2007).

Agriculture is the major water user. This economic activity accounts for 90% of total water used in the area, and in the last twenty years unsustainable pumping rates have lead the region to an overexploitation of the main aquifer (Acuifero Principal). This aquifer supplies 85% of the total agriculture groundwater demand, and the remaining 15% supplies the total water requirements for cattle, industrial and domestic water demand (CNA, 2002, 2004, 2008; SEMARNAT, 2003). Given the proportions of water use for different economic activities, and the regional participation of the nation's agricultural and cattle production, it would be expected to account for a large proportion of Gross Regional Product (GRP), however, the agriculture sector represents only 6.8% of GRP from the region, while the industry and services sectors represent 93.2% (Garcia and Guzman, 2007). Agriculture and cattle production alone do not bring wealth to the region, and they consume 90% of the water resources. Water pricing schemes and allocation of water considering the benefits and the highest economic value of water use,

have been irrelevant or not 'socially acceptable' to water planning strategies in the Laguna region.

Legal Framework for Water

In Mexico, water use has been historically tied to the principal that water resources are the property of the state. This concept comes from land reforms established in 1917 in Article 27 of the Mexico Constitution. Since 1988, Mexico has undergone a revolution in the laws allocating its water resources and regulating its quality. Recent reforms are designed to promote private water rights, allow for the privatization of management of water supply and wastewater services and incorporate new principles, such as a requirement to conduct cost-benefit analysis in the application of regulatory standards.

In 1992 the country adopted the Ley Nacional de Agua (LNA) that reaffirmed federal water rights systems and established federal and state and basin water management agencies. The Comisión Nacional del Agua (CNA) is responsible for water policy, water rights, planning, water supply, irrigation and disaster planning. The Ministry of Environment and Natural Resources (SEMARNAT) has the responsibility for managing the CNA. State water commissions (CEA's) do have some authority for managing water public water supply and public water treatment systems. Basin Authorities (BA's) are regional offices of the CNA established to work at a regional level on planning and policy development.

The 2004 amendments to the LNA transfer some managerial and planning responsibilities from the CNA to regional basin agencies in order to decentralize some of the planning, research and management responsibility from Mexico City to different regions of the country. However, the final authority for planning and management still resides with the federal government (Scott and Banister, 2007).

The LNA sought to change the method for allocation of ground water throughout Mexico. It restricts the granting of new water rights on fully appropriated basins. This change is expected to create a market for water rights (National Research Council, 1995). The effectiveness of the law partly depends upon the knowledge of how much the

previous user was actually using. If implemented properly, this new law should be useful in controlling groundwater extractions in highly exploited areas by limiting the availability of permits.

This dissertation offers an exploratory analysis of the issues in the decentralized planning process as it relates to aquifer depletion in the Laguna region. Issues related to data accuracy, trust and communication are important elements in this process.

THE PROBLEM

Data from the CNA and from local well logs indicate that the current groundwater pumping rates are resulting in a dramatic decline in the water level of the aquifer and in the region's water supply. Preliminary studies indicate this decline is not sustainable and if continued will lead to reduced water availability and dramatic shifts in the regional economy. Irrigated agriculture, as the dominant sector of the economy, could be significantly impacted as less water will be available for this use. As a result of mining, water quality is also diminished. Figure 2.7 illustrates the pumping levels in 1963, which show a maximum of 50 meters. Figure 2.8 shows the cumulative reduction of water pumping levels in the Acuifero Principal over the last 60 years and the condition on 2005. Red areas show pumping levels above 100 meters.

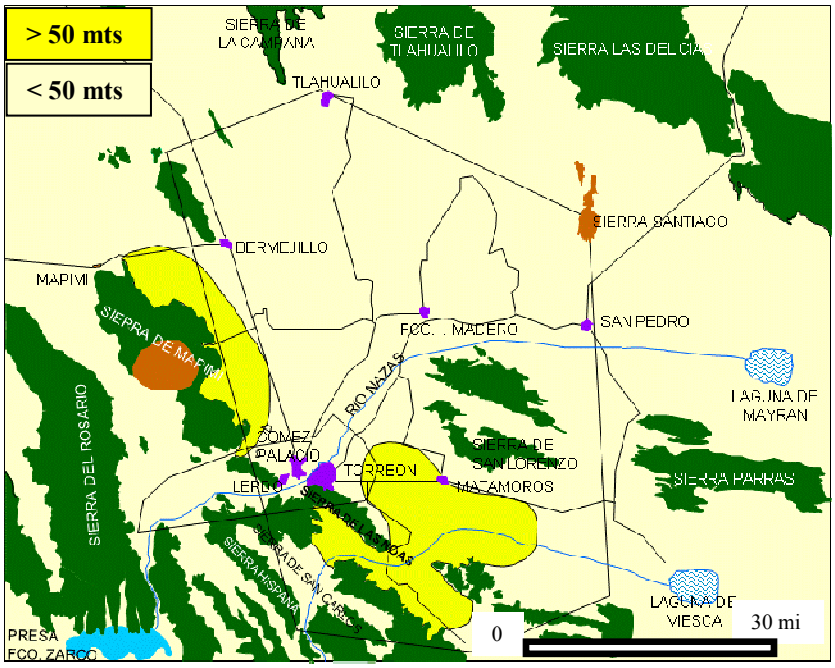


Figure 2.7 Pumping Levels at the Acuifero Principal in 1963. Areas in yellow concentrate pumping levels above 50 mts (CNA, Cuencas Centrales del Norte, 2005).

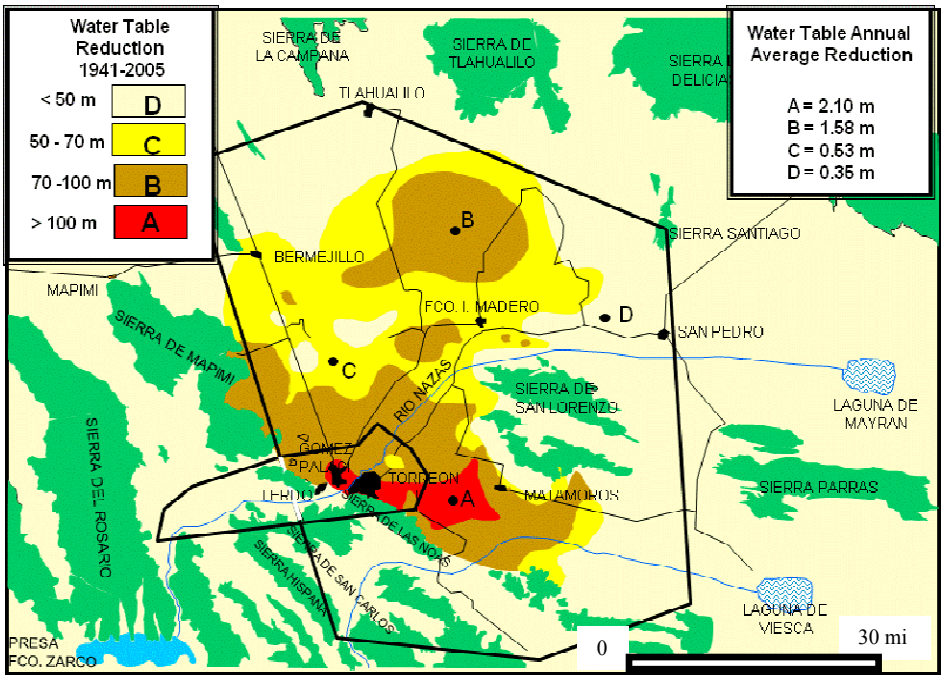


Figure 2.8 Pumping Levels at the Acuifero Principal in 2005. Colors show cumulative reduction of pumping levels since 1963 and average annual reduction of the water table. (CNA, Cuencas Centrales del Norte, 2005).

Some academic analyses indicate that water quantity crisis collapsed twenty years ago when the federal government restricted for the 5th time, new drillings in the area with a consequent decrease in the pumping rate from 1,700 to 1,100 Mm^3 (CNA, 2002, 2004; Hernandez, 2008). However, that reduction was not enough for the aquifer's sustainability and certainly not enough for all agricultural users, because not everyone could afford extracting from declining pumping levels. According to the CNA projected scenarios for the region, a sustainable scenario for water use for the following 20 years will require a reduction of 30% of groundwater use and 17% of surface water, which means a total of approximately 50% reduction of total water use in the region (CNA, 2007). Figure 2.9 depicts the storage levels over the last 15 years in the largest reservoirs in the region (Lazaro Cardenas and Francisco Zarco), showing mean gradual decreasing levels of storage given a decrease of rainfall in the region over the last two decades (CNA, 2007). What this illustrates is the fact that the reduction of surface water availability for future demand increases the dependency on groundwater in the long term threatening even more the actual mining condition of the aquifer.

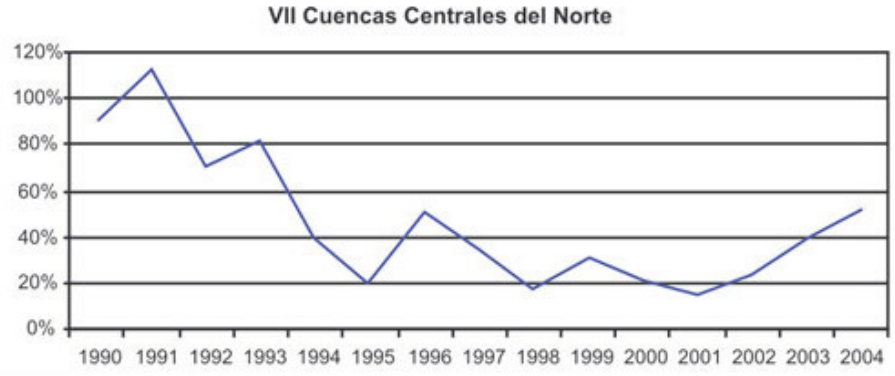


Figure 2.9 Water Storage Levels of Main Reservoirs in the North Central Basins. (Lazaro Cardenas and Francisco Zarco reservoirs) (CNA, 2007).

Today, the water quantity crisis includes also the quality issue. The crisis is now extended to potable water users, which for obvious reasons are the most vulnerable sector. The increase of arsenic, sulfate, calcium, sodium, lead, lithium and nitrate

concentrations beyond national permissible levels has lead the issues of water availability to become a sensitive health concern of regional and national dimensions, putting the issue of water-scarcity in the everyday social, economical and political regional claims (SEMARNAT, 2003; Hernandez, 2008).

The stress condition of water availability and quality of the most important resource for the continuity of economic development of the region, is well known by the actors involved (Mena, 2008). However, jurisdiction problems, legal ambiguities, lack of consensus over the alternatives, fragmentations of different interests over resource and power differences, have elevated the problem to a steady-state condition in which "crisis" cannot define the actual situation of water sustainability since other priorities still lead the agenda. Those other priorities depend on the parties involved, the distribution of power among them and jurisdiction limits. The way in which sectors are involved in the issue is rather complex, fragmented and power driven (Castañon, 2005; Hernandez, 2005; Romero and Jimenez, 2005; Hernandez, 2008).

PLANNING LITERATURE ON THE LAGUNA REGION

According to the literature, there is no official estimation of groundwater reserves in the Laguna region for the next 20 or 40 years, however there is an estimation of a total depletion of the aquifer in the next 45 years (CNA, 2002), even though there is no deep analysis on the methodology on how they obtained this figure. Official and academic research coincide on estimations of annual pumping rate of 1,100 Mm^3 and recharge rate of 518.9 Mm^3, which show an actual deficit of around 600 Mm^3 per year. This extraction rate represents an aquifer in a mining condition, a reduction of the water table that has varied from 30 to 120 meters since the 1940's, and an average annual reduction of 1.8 to 3 meters (Cruz and Levine, 1998; CNA, 2002, 2004, 2008; Hernandez, 2006; Garcia and Guzman, 2007).

According to the literature reviewed, water-scarcity planning research in the Laguna region is practically nonexistent. Literature is limited to hydrological studies in the region, water pricing regimes and some historical analysis of the absence of groundwater regulation (CNA, 2000; Whiteford and Melville, 2001; Navarrete and

Melville, 2004; Descroix *et al*., 2004; Hernandez, 2004, 2006, 2008; Escolero, 2006). The studies related to levels of extraction in the region come from a broader perspective that includes the northeastern region, and the smallest level of analysis includes two states (Coahuila and Durango). So, information on water use, quality, and policy development over these issues has been mainly controlled over national standards instead of regional standards, though some research has been done on legal framework analysis (Hernandez, 2004, 2006). There are also historical assessments on water use in the region and its social and economic contextual considerations and cultural approaches related to the *Laguneros* and their relationship with water, economic development and globalization (IFIAS, 1988; Salas, 2002; Martinez *et al*., 2003; Corona, 2005; Wolfe, 2006; Hernandez, 2006). The reports of the CNA from 1994 to 2002 offer mainly regional analysis, and they do not offer technical or critical information about specific cases, such as groundwater regions or specific aquifers, except the 2002 CNA report on water availability of the Acuifero Principal. Recently, the CNA published a research study based on a water availability model of the basin to predict tendencies over two scenarios for a 30 year period: actual conditions and sustainable assessment. This research will be used to estimate moderate and critical scenarios of water availability in Laguna that will be offered to interviewers (CNA, 2007).

What is known about this topic is very general and it only gets specific when it comes to dairy and meat production, which are generally related to the economic value of the region and its productivity importance for the northern part of the country, but not necessarily related to the water stress condition in the region. The work by Whiteford and Melville (2001), Descroix *et al.* (2004) and Constantino (2006), are a few publications that touch upon the challenge of water scarcity on growing urban centers in Mexico, the sustainability of recharge areas, and the changing role of states and cities to be more proactive in the development of new regulations to protect water resources, though they do not deal specifically with planning for a water-scarce condition. The text by R. Ahlers *et al.* (1999), deals specifically with the Laguna region and analyses discrepancies between national level policy and local implementation, where market

'informalities' come into place and water allocation under neoliberal logics locates the problem of policy development in a secondary priority place. This work is also considered by Hernandez (2006) and Hernandez C. (2006). This shows at least one sign of contextual consideration for water planning.

There are also national papers that refer to the history of water regulation on the Laguna region (Navarrete and Melville, 2004; Hernandez, 2005), which deal with the historical relationship between groundwater regulation, economic development and national events, and give a general overview of how the policy development had to be adapted or restrained by the economic priorities or the predominant interests of the region. The literature that addresses the different subjects related to the overexploitation of the Acuifero Principal is mainly related to the subsequent economic activities that are sustained by groundwater extraction: the diary and meat industry in the region and their socioeconomic impact on the region, which is highly important for the region's development (Villarreal *et al*., 1998; Aguilar *et al.,* 2002; Jimenez *et al*., 2006; Garcia and Guzman, 2007). It is important to mention, that literature is mainly national; there are practically no foreign studies that addresses water management issues. Actually, there is more analysis on the fact that there is no data, that on the issue that there no interest in dealing with planning policy issues. There are no sustainable models considered or vulnerability assessments in the region. Moreover, there are only few studies on the efficiency of irrigation systems in the region and water pricing (Fortis and Alhers, 1997; Montemayor *et al.,* 2004; Rodriguez and Orona, 2005; Guzman *et al*., 2006), and subsequently, there are no alternative analysis of possible scenarios of a different policy strategy that can possible ameliorate the water stress condition in the aquifer (Rochefort and Cobb, 1994; Cruz and Levine, 1998; Hernandez, 2004; CNA, 1986, 2002, 2004); Hernandez, 2006; Guzman *et al.,* 2006; Garcia *et al*., 2006).

Planning and policy development under a water scarce condition in the Laguna region have meant a failure not only from a water management perspective, but from a social-political approach (Romero, 2004; Hernandez, 2004). Not only the region has followed an increasing rate of overexploitation of the groundwater over the last fifty

years, but the policy over water resources has experienced over the last twenty years a process of informal practices among water users caused by a poor, centralized and inefficient policy system. However, it is precisely this poorly regulated "condition" that has impeded the development of a more integrated, updated and, for some sectors, fair and equitable policy (Sanchez, 2007, unpublished data). Since 1992, when President Salinas de Gortari amended the Constitution and gave to the traditional legal figure of the "ejido" (collective land) the quality of a marketable good, land distribution moved from a traditional and collective ownership to a less but more concentrated private users one. Official numbers show that eighty per cent of the Laguna wells –around 2000- belong to one user: LALA dairy company (Romero, 2004; Hernandez, 2004; Jimenez *et al*., 2006).

The lack of consensus on problem identification, the eroded institutional leadership among and between federal and state jurisdictions, the economical efficiency assumptions over an unequal distribution of wealth and access to water resources, and political implications, have raised questions like: under a water scarce condition, what planning policies could be successful when considering different users under different economical, political and social conditions? What are the options that different users have when they face water scarcity? Is it water being scarce the problem behind a water scarcity claim? Could the Laguna region be an example of a driven-water scarce crisis? And most importantly, what exactly is more vulnerable for the region: the lack of water resources or the lack of planning policies? What is the preference, expectancy and feasibility of different water users? As it is well known by people in the area: "Everybody knows we are running out of water, but everybody knows we cannot do anything about it" (Mena, 2008).

In previous years, the CNA has emitted recommendations on planning policies to address the overexploitation of the Acuifero Principal in the region, however, none of these have produced any impact to local planning; on the contrary, federal (mainly presidential decrees) regulations have promoted an increase of subsidies in energy consumption, encouraging pumping and worsening even more the condition of the

aquifer (UNDP Report, 2006). What is needed is an understanding of the vulnerabilities both from a quantitative and qualitatively approaches behind a water-scarce condition, and to define key contextual characteristics that could help develop a more successful planning assessment for the Laguna region.

LITERATURE ON WATER PLANNING

The literature on planning under or for a water scarce condition is not extensive. However, if planning for drought is considered as part of a water scarce condition case, then the work by Wilhite *et al.,* (1987, 1993, 2001, 2004) appears as the most important reference for planning, mitigation and preparedness for drought, mainly in the United States, but has also addressed study cases in India, China, Israel (Wiener, 1964), South Africa (also see Herbolond, 1993) and Australia (also addressed by Boughton, 1991). Likewise, other research work has been completed in Africa, mainly in Ethiopia (Ottaway, 1986), Kenya (Iro and Long, 2007; Smucker and Wisner, 2007) and Canada (Wheaton *et al*., 2008).

In the case of Mexico, there is a paucity of literature on planning for water scarcity; the research is focused mostly on analyses of drought impacts, adaptation and vulnerabilities (Liverman, 1990, 1999), and lessons learned by scarcity on the Rio Grande basin (Mumme, 1999; Chavez, 1999). There are also official water-scarce planning and cause analysis presented by the United Nations Development Program (UNDP Report, 2006) focused on underdeveloped countries, and by the Economic Commission for Latina America and the Caribbean (CEPAL, 1994).

For planning policy purposes, the literature is focused on planning for drought as a particular water-scarce event, but it does not go beyond the issue of water scarcity as a permanent condition. This dissertation uses planning for drought as part of the planning process for a water scarce crisis and offers different conceptual differences of a permanent water-scarce condition considering not only hydrological, socio-economical, climatological factors, but also economic and social aspects (Anderson and Woodrow, 1991; Wisner *et al.,* 1994; David, 1996; Knuston *et al*., 1998; Liverman, 1999; Homer-Dixon, 2000; Britton and Ford, 2001; Watson, 2003; Abraham, 2006).

The literature on planning for drought or scarcity conditions can be divided into two areas: risk management and crisis management. Planning policies are concentrated mostly on crisis management and there is little on risk management part (Wilhite, 1993, 2001). The main reasons of this lack of preparedness for a water-scarce condition have to do with policy-decision making processes and political priorities (Wilhite, 1993; Rouyer, 2000; Kingdon, 2003). Recent researchers agree on the responsibility of policy development of planning strategies to assess higher vulnerabilities for worsening scenarios of water scarcity, mainly in arid and semiarid regions.

Two important gaps have been identified in the literature reviewed that could be important to understanding the absence of planning polices for a water-scarce situation. The first has to do with differences in conceptual definitions of drought and water-scarcity. According to Wilhite (1987), there are four types of droughts: meteorological, agricultural, hydrologic and socioeconomic droughts. However, as Wilhite recognizes, one of the main reasons of lack of planning policies is precisely that there is no consensus on the definitions of drought , because indexes do not apply equally everywhere and we usually identify a drought when it is already happening (Wilhite, 2000). A drought definition usually comes with a "crisis" adjective for political and policy strategy attention. On the contrary, water-scarcity conditions cover drought definitions and also, can be considered as permanent "condition" depending on the analyzed case; in this scenario, it is less likely that planning strategies play an important role for political priorities (Rochefort and Cobb, 1994; Kingdon, 2003).

The second gap has to do with the perspectives of scarcity for different uses and users. The work done by Aaron Wolf (1995, 2006) which deals with the idea that the next wars will be over water, has opened new windows of research of water meanings. As he states: "There is a difference between water as a source, as a resource and as a weapon" (Wolf, 1995). The issue of water scarcity as cause of violent conflict is recent, but has taken the water-scarce issue to a higher correlation with political and economic matters, than to hydrological considerations; the case of the Israel-Palestinian conflict is

the study case example used by most literature (David, 1996; Rouyer, 2000; Dinar, 2000; Elhance, 2000; Wolf, 1995; Wolf *et al*., 2006; Haddadin *et al.,* 2006).

For example, at a nation level, a water-scarce condition in Australia will not mean the same thing in Kenya. In the first case it would mean the need for more investment in irrigation techniques and the use of governmental programs to protect losses (Boughton, 1991); in the case of Kenya, it likely entails migration to the closest neighbor to survive the famine (Iro and Long, 2007). From a regional perspective, water scarcity has not been fully analyzed from the perspective of equity. The wealthiest part of the population will never experience a water-scarce condition to the same degree as the poorest part (Liverman, 1999; Rouyer, 2000). From this perspective, water scarcity must be also analyzed from the users' perspective.

The literature regarding vulnerability is broad, as it covers all kinds of societal vulnerabilities. Specific water-scarcity vulnerability is addressed by Anderson and Woodrow (1991), Wisner *et al.,* (1994) David (1996), Knuston *et al.,* (1998), Liverman (1999), Homer-Dixon (2000), Ford (2001), Watson (2003) Abraham (2006), Wilhite *et al.,* (2007), and others. It is the work by Homer-Dixon that will help develop this dissertation's qualitative approach model to define the level of vulnerability by measuring the relationship between contextual factors and water scarcity since he already recognizes the importance of political, social and economic factors; this dissertation will try to measure the weight of the main factors to determine planning priorities. Likewise, when trying to measure and evaluate the potential for sustainability in the region, definitions based on the 1988 Declaration the UN Food and Agriculture Organization (FAO) will be used and complemented with the regional definitions and sustainable assessments by Descroix *et. al*., (2004), Constantino (2006), Hernandez (2006), Hernandez C. (2008), Valdés (2008).

RESEARCH METHODOLOGY

This dissertation used multiple means and measures to collect and analyze the data. One set of primary data for the dissertation was collected based on personal interviews with selected federal, state and local appointed and elected officials,

municipal and agricultural water users. The interviews were recorded and transcribed. A second set of primary data was collected from a questionnaire distributed to the interviewee's and to an expanded list of water stakeholders in the Laguna region. This list was expanded to provide data to analyze the data from a statistical perspective. A third set of secondary data on economics, agricultural production and water availability was used in order to construct a model of outcomes using STELLA software. This data was taken from federal and state data sources.

Personal Interviews

A sample of water managers, water users and academics or experts was selected for interviews. These three groups were selected from different levels of government and knowledge on the issues related to water-scarcity in the region and asked about possible planning strategies that could alleviate the problem among the fifteen cities in the Laguna region. The three largest populated cities (Torreon, Gomez Palacio and Lerdo account for 85% of total regional population), plus another four (Mapimi, San Pedro, Matamoros and Francisco I. Madero), concentrate 70% of water wells, cover 58% of land use for agriculture and cattle production and consume 96% of urban water use in the region (Garcia and Guzman, 2007). A total of 30 people within the three groups in the two states and the seven cities were selected based on the above criteria of representativity (See Table 2.3).

Table 2.3 Distribution of Interviews among Sectors in the Laguna Region.

Categories	**Sectors**	**No. of Interviews**
Federal	Coahuila, Durango	2
State	Coahuila, Durango	2
Cities	Torreon Mapimi Gomez Palacio (2) Fco I Madero Matamoros Lerdo	7
Water users	Industry	2
	Private farmers	3
	Ejidos	3
	Urban (Torreon, Gomez Palacio)	2
Academics	Private and Public	9

The following questions were posed to the interviewees.

1. First question:

   What is your opinion on the condition of water resources in the Laguna region?

2. Second potential questions:

   Is there a problem?

   Which do you consider are the reasons why there is an x problem?

   What institutions or people are the responsible for this condition?

3. Third potential questions:

   What has been done successfully or unsuccessfully?

   What scenarios do you see coming for the region?

   What would you recommend?

4. Fourth potential questions:

   What would you be able to give up in a critical or moderate crisis?

5. What planning strategies do you recommend?

The interview data was analyzed based on the grounded theory method to identify the alternatives chosen by different sectors under different scarcity scenarios and used to develop a qualitative assessment. This method was discovered by Glaser and Strauss in 1967 and is defined as an emergent theory that uses systematic qualitative data to generate theories. The theory process development uses the inductive method to generate concepts, categories and propositions from a constant analysis, comparisons and development of theoretical relationships. Grounded theory is not generated *a priori* and then subsequently tested (there are no hypotheses tested). Rather, it is "inductively derived from the study of the phenomenon it represents. That is, discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory should stand in reciprocal relationship with each other. One does not begin with a theory, and then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge" (Strauss and Corbin, 1990).

Theories or propositions will be developed as the data from the interviews starts to fit patterns of human attitudes, behavior, opinions and preferences around the issue of the water-scarce vulnerable condition. The result, in the words of Glasser, "will be transcending abstraction, not accurate description…Abstraction frees the researcher from data worry and data doubts, and puts the focus on concepts that fit and are relevant" (Glasser, 2002). The process of grounded theory building used is adapted from Pandit (1996).

Questionnaire on Preference/Feasibility

A second set of primary data was collected from questionnaires distributed to the interviewee's and to additional water users in the Laguna region. The additional users were from an expanded list in the same proportion as those in the three interview groupings. A total of 67 officials and users received the questionnaire. This sample size was based on time and cost limitations as well as a significant level of reliability based on a confidence interval of 90% and a 10% of margin error.

The objective of the questionnaire was to measure levels of preference and feasibility of planning strategies identified in the previous analysis in order to identify the best and least alternative for the region as a whole and for the different analyzed groups. The interviewers answered questions related to levels of preference and feasibility (adapted from Kaiser, 2000 and Collins, 2000). See Appendix A for a copy of the questionnaire. The preference feasibility analysis (PFS) is useful because it provides an indicator to measure how much people like strategies and more importantly, whether the ideas are realistic (Collins, 2000).

These results are plotted on a Preference-Feasibility Action grid divided in four quadrants (see Figure 2.10). Each quadrant represents different levels of preference and feasibility. Strategies in the upper right corner are strongly preferred and highly feasible. The lower right quadrant will contain strategies highly feasible but not very preferable. The upper left size contain strategies strongly preferred but not very feasible. The lower left size will point the strategies that need to work on both preference and feasibility.

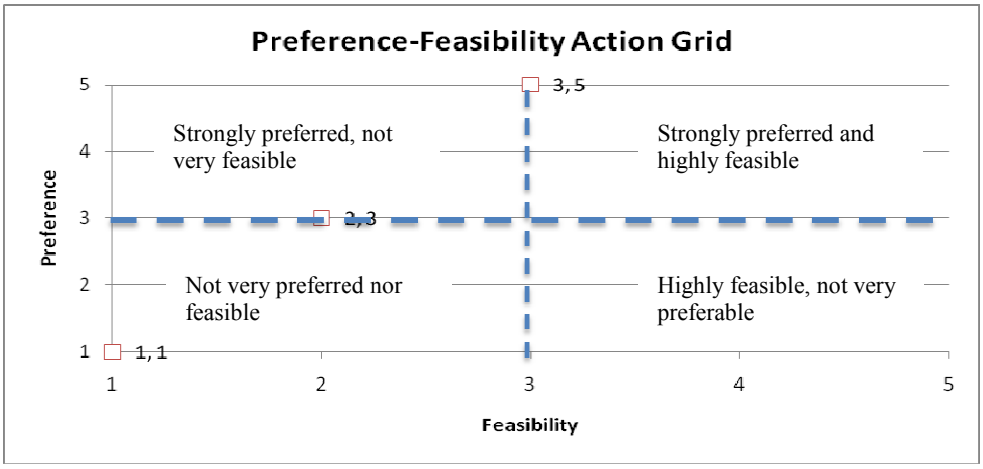


Figure 2.10 Preference and Feasibility Action Grid. (Adapted from Collins, 2000).

Secondary Data

Secondary data, used to develop the economic vulnerability model, was derived from federal and state statistics on water use, agricultural production and economic data.

The quantitative model uses systems theory approach with Stella software to measure the economic vulnerability of a water availability condition of the aquifer in the Laguna region, and considers climatic conditions (drought and hurricane possibilities), and uses the model to estimate impact on water savings and/ or economic benefit from the planning strategies chosen by the interviewers in the first round.

The most extensive economic estimations and productivity related to water use in the region is addressed by Garcia and Guzman (2007). This work will be the basis for the model that this dissertation will develop to measure economic vulnerability of the region to water scarcity, based on the systems theory perspective by Grant and Swannack work of 2007.

This dissertation will also use main agriculture activities in the region (meat and milk industry) because they use 90% of the water from the aquifer. Included will be water availability, water use, price per kgs or lts, recharge rate and a climate stochastic variable as the main drivers. Main assumptions will be: quality of water does not change, prices are constant, water requirements per ton are constant and, because there is no information regarding the actual volume of the aquifer, four scenarios of water availability considering depth, area and different porosities, will be used to estimate water reserves. Simulations of seventy years will be carried out to predict the water availability and to measure corresponding economic impact (Grant and Swannack, 2007).

To summarize, the several analyses and processes that will be used for this research will offer different outputs. From the first grounded theory process of interviews and qualitative data collection, the data analysis will show the level of vulnerability of the region to scarcity, the reasons for that vulnerability, and it will point out possible strategies to overcome the issues. From the second quantitative data collection and questionnaire survey process, the data will point out the most preferred and feasible strategies in the Laguna region with a statistical significant level of confidence.

III. POSSIBLE EFFECTS OF DROUGHT-INDUCED CHANGES IN GROUNDWATER AVAILABILITY ON ECONOMIC VALUE OF AGRICULTURAL PRODUCTION IN THE LAGUNA REGION, MEXICO

SYNOPSIS

The Laguna region is considered the second largest productive area in the northern part of Mexico. At national level, the region ranks first place in production of: sorghum forage, cantaloupe, alfalfa, and bovine and goat milk. It is the most important meat industry in the northeastern part of the country. Economic development in the region is sustained mainly by the overexploited Principal Aquifer, which supplies 85% of the total groundwater use for agriculture and 100% for cattle production. This dissertation presents a stochastic simulation model that offers projections of agriculture production value in the region based on several estimations of actual water volume in the aquifer. It also explores the effects of droughts and hurricanes in the region. Results reflect a significant difference between projections of water reserves and production value. It also shows differences in production value due to an increase of drought probabilities (10 to 20%), and it shows that hurricanes significantly contribute to economic production values.

INTRODUCTION

Worldwide, groundwater is about 70 times greater than all surface water, and more than half of the world's population today depends on groundwater for its basic needs (Eckstein and Eckstein, 2005). Groundwater constitutes 96% of unfrozen freshwaters, around 60% is used for agriculture in arid and semiarid climates, and it supplies approximately one third of the water-drinking needs (UNESCO, 2007). These facts have not only challenged research and technology development to understand the logics of groundwater hydrology, but have revealed the urgent need to develop new sources of water availability, given the already saturated use of surface water and the increasing mining condition of aquifers around the world. Currently, 1 of every 6 people

has no access to safe drinking water and it is estimated than by the year 2025, two thirds of the world population will suffer from critical to moderate water stress condition (UNESCO, 2007).

In Mexico, 1 of every 6 aquifers is overexploited and half of them show increasing levels of salinization (CNA, 2004). In the State of Coahuila, where 90% of groundwater is used for agriculture, the condition gets even worse. Close to 60% of the aquifers are overexploited and have some level of water degradation. Today, the State is considered to be under a water-stress condition and predictions have estimated a severe water stress condition by the year 2025 (CNA, 2004).

The Laguna region, an area of 4.79 million hectares (ha) between the states of Coahuila and Durango, represents a key study case for several reasons. First, it is considered the second largest land and water productive area in the northern part of Mexico, just after the Delicias desert in Chihuahua. At the national level, the region ranks first place in production of sorghum, cantaloupe, alfalfa, bovine milk, and goat milk, and 10% of cattle production (Garcia and Guzman, 2007; SAGARPA-INIFAP, 2007). Secondly, economic development in the region is sustained mainly by *El Acuifero Principal* (the Principal Aquifer), which supplies the total water use for cattle, 98% of industrial, 97% of urban-domestic and 85% of agriculture use (SEMARNAT-CNA, 2004; CNA, 2007). Third, the mining of an aquifer to sustain a semiarid region of 1.5 million inhabitants that faces water shortages permanently and that is threatened by longer droughts due to climate change scenarios (Liverman, 1990, 1999; Ward, 1995; Borroughs, 2007; IPCC Report, 2008), represents a common challenge scenario for water managers and planning policy development in present years. And, most importantly, the institutional response to the actual condition has been deficient, based on political interest, planned only for the short term, and it has not ameliorated the unsustainable groundwater extraction rate in the region (Whiteford and Melville, 2001; Romero and Melville, 2004; Hernandez, 2004). These characteristics offer a typical example of numerous semiarid regions around the world that depend on groundwater for

agriculture production as their main source of economic development, and that at the same time, this productivity is threatened by the vulnerability of the hydrological cycle.

The literature on the Laguna region offers general concerns over two main aspects: the mining of the Acuifero Principal, which has led to the deterioration of water quality as well, when at higher depths of extraction, the increased concentration of minerals such as arsenic, and the general concern of the present and future sustainability and vulnerabilities of economic activities of dairy and cattle industry in the region, due to aggressive low estimations of groundwater availability in the next 20 to 45 years (IWMI, 1997; CNA 2002, 2007; SEMARNAT-CNA, 2004; Descroix *et al*., 2004; Valdés, 2008). However, there has not been much analysis on the economic impacts that can take place due to a reduction of water availability over the next decades, and the possible dramatic changes of climate that might not be even considered by the actual estimations of water availability.

The nine main agricultural products in the Laguna Region that will be considered in this paper include alfalfa, maize forage, oat forage, sorghum forage, cantaloupe, bovine milk, goat milk, bovine meat, and chicken meat. The five crops use approximately 85% of total water use for agriculture and the four cattle products consume 95% of total cattle water use in the region (Garcia and Guzman, 2007; CNA, 2007). At the same time, these nine products represent 75% and 90% of total agricultural and cattle production value, respectively (Garcia and Guzman, 2007; CNA, 2007).

This paper examines the possible effects of drought-induced changes in groundwater availability on the economic value of agricultural production in the Laguna Region. More specifically, we examine the possible effects on production of the nine main agricultural products under several assumptions regarding future increases in the frequency of droughts in the Region.

MATERIALS AND METHODS

To determine quantitatively the possible effects of hurricanes and future increases in the frequency of droughts on the economic value of agricultural products in the Laguna Region, a discrete-time simulation model was developed based on estimates

of allocation of water among, and water use efficiency and market price of, the nine main agricultural products in the Region (Garcia and Guzman, 2007; SAGARPA-INIFAP, 2007) (Table 3.1).

Table 3.1 Estimates of Allocation of Water, Water Use Efficiency and Market Price of the Nine Main Agricultural Products in the Laguna Region. Estimates are based on information in Garcia and Guzman (2007) and SAGARPA-INIFAP (2007).

Product (Production Unit) (*i*)	**Allocation of Water (%) (P_i)**	**Production Efficiency (Production Units per Mm^3 of Water Allocated) (WR_i)**	**Mean Market Price (Pesos per Production Unit) (EV_i)**
Alfalfa (metric ton)	67.8	4,863	250.00
Forage Maize (metric ton)	13.57	3,777	210.00
Forage Oats (metric ton)	7.11	5,571	230.00
Forage Sorghum (metric ton)	4.43	3,660	200.00
Cantaloupe (metric ton)	2.66	2,042	1,171.00
Bovine Milk (l)	1.73	130,983	3.6
Goat Milk (l)	0.17	52,146	3.2
Bovine Meat (kg)	0.98	5,990	24.7
Chicken Meat (kg)	1.55	20,792	14.3

The model was formulated as a stochastic compartment model based on difference equations (Δt = 1 year) and programmed in STELLA® 7 (High Performance Systems, Inc.). The conceptual model is shown in Figure 3.1.

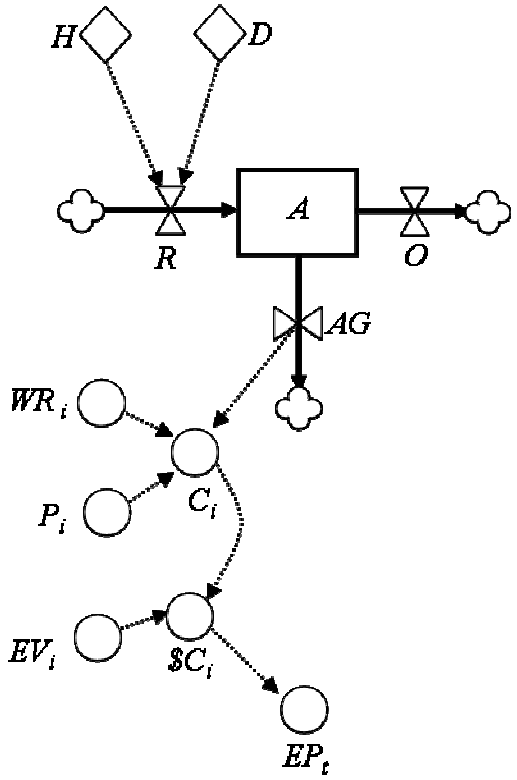


Figure 3.1 Conceptual Stella Model Representing the Dynamics of El Acuifero Principal. *A* (aquifer) as a function of recharge (*R*), water use for agriculture (*AG*) and other water uses (*O*). The second sub-model (*C*) represent the production in tons and/or kilograms of the nine different products (Alfalfa, Maize Forage, Oat Forage, Sorghum Forage, Cantaloupe, Bovine Milk, Goat Milk, Bovine Meat and Chicken Meat), which is a function of percentage of water use per type of product (*P*) and the water requirements per ton or kilogram-liters of production of each product (*WR*). The third sub-model is represented as the total production value (*EP*), which integrates the total price value of the total of production in tons and kilograms-liters of the nine products (*EV*).

The dynamics of *El Acuifero Principal* (*A*) were represented as:

$$A_{t+1} = A_t + (R_t - AG_t - O_t)\Delta t \qquad (1)$$

Where A_t represents the amount of water in the Acuifero Principal at time t, R_t the recharge at time t, AG_t the amount of water extracted for agricultural and cattle uses, O_t the amount of water extracted for other, non-agricultural uses, and Δt represents the change in time, in this case, 1 year. Since there are no definitive estimates of current groundwater reserves in the Laguna Region (SEMARNAT-CNA, 2004), possible drought effects were examined under four different assumptions regarding total area of the aquifer, depth of the saturated zone, and porosity (Table 3.2); note this paper considers only the Acuifero Principal, which accounts for 85% of total groundwater use in the Region (Garcia and Guzman, 2007).

Table 3.2 Scenarios Regarding Current Water Reserves in the Acuifero Principal in the Laguna Region. Information based on the indicated assumptions regarding size of the recharge area, and depth and porosity of the aquifer (CNA 2002,SEMARNAT-CNA 2004, Hiscock 2006).

Scenario	**Area (km)**	**Depth (m)**	**Porosity (%)**	**Total (Mm^3)**
1	14,505	40	25	145,050
2	14,505	40	15	87,030
3	4,500	50	25	56,250
4	4,500	50	15	33,750

The porosity ranges were estimated considering the type of material of the aquifer, which ranges from alluvial in its more permeable layer, to fine limestone in the medium permeable zone, to gravel and lacrustine sediments in the lower less permeable layer (CNA, 2002; SEMARNAT-CNA, 2004; Hiscock, 2006).

Extraction of water for agriculture and cattle (AG) or other (O) uses were represented as linear functions of the amount of water available in the aquifer. We assumed the annual rate of water extraction for AG will decrease linearly from 830 Mm^3 (Millions of cubic meters) to 0, which is the actual extraction rate of the aquifer for

agriculture and cattle use (SEMARNAT-CNA, 2004; CNA, 2007; Garcia and Guzman, 2007):

$$AG_t = 0.0063 * A_t \quad (2)$$

The rate of water extraction, assumed for *O,* will decrease linearly from 378 Mm^3 to 0, which corresponds to the rest of groundwater extraction for industrial and urban-domestic use (SEMARNAT-CNA, 2004; CNA, 2007; Garcia and Guzman, 2007**)**, as water reserves in the aquifer decrease from 145050 Mm^3 to 0 (maximum estimation accounting for an area of 14,505 km^2, 40 meters of depth and a porosity of 25%) (SEMARNAT-CNA, 2004; Hiscock, 2006; CNA, 2007; Garcia and Guzman, 2007).

$$O_t = 0.0029 * A_t \quad (3)$$

It was also assumed the full volume of water in the aquifer is available, regardless of water quality, soil conditions, or pumping costs.

The annual rate of recharge (R) of the aquifer depended on climatic conditions (i.e., droughts (D) and hurricanes (H)). This paper assumed that recharge during non-drought, non-hurricane years was 518.9 Mm^3, about half of which comes from precipitation, with the other half coming from irrigation, urban runoff, and horizontal recharge, and that annual recharge would be reduced by 50% during drought years (CNA, 2002).

For remaining conditions, R_t was calculated as:

$R_t = (518.9 * 0.5) + (518.9 * 0.34)$ if H=1, D=1 (4a)

$R_t = 518.9 * 0.5$ if H=0, D=1 (4b)

$R_t = 518.9 + (518.9 * 0.34)$ if H=1, D=0 (4c)

H = 1 and D = 1 represent a hurricane and/or drought occurring during a time step. Historically, droughts have occurred in the Region about every 10 years, with an average duration of four years (Cruz and Levine, 1998; CNA, 2004). Thus, this paper assumed a

10% chance of a drought beginning in any given year, and the simulated droughts had an equal chance of lasting 2, 3, 4, 5, or 6 years. It was assumed hurricanes occurred at historical frequencies (Cruz and Levine, 1998; CNA, 2004, 2008) and the probability of a hurricane occurring during any given year was 0.16.

This research led to the development of a relatively simple economic model to determine how the frequency of droughts would affect the economic production of the Laguna Region. Market prices were assumed, in pesos, and the nine products ($\$C_i$) remained constant during simulation, and economic value (EV_t) is measured only in terms of market prices. Economic production of the Region was a function of AG_t as well as the percentage of water use per type of agricultural product (P_i), and the water requirements per ton or kilogram-liters of production (WR_i) (Table 3.1). Equations 5 – 7 represent our calculations of economic production per unit time t (EP_t):

$$C_{i,\,t} = WR_i * P_i * AG_t \quad (5)$$

$$\$C_{i,\,t} = C_{i,\,t} * EV_i \quad (6)$$

$$EP_t = \Sigma\$C_i \quad (7)$$

where i represents each of the nine agricultural products in the model.

Changes in water reserves in the aquifer were simulated over a 70-year period, under the assumptions described above, using a simple stochastic compartment model based on difference equations ($\Delta t = 1$ yr), programmed in STELLA® 7 (High Performance Systems, Inc.). 17 replicate stochastic (Monte Carlo) simulations were run under each of the four assumptions regarding current water reserves in the aquifer (Table 3.2), which allowed detection of a difference of 2 million pesos over a period of 70 years (sample size formula from Ott and Longnecker, 2001). Then the same dynamics were simulated, but the probability of drought was increased to 0.20 (any one drought could last 2, 3, 4, 5, or 6 years, as above). Significant differences in mean economic values among scenarios were tested for using ANOVA as well as specific directional differences using a LSD post-hoc test.

RESULTS

The greatest difficulty in projecting future trends for the economic productivity generated from agricultural production of the Laguna region is related to uncertainties concerning (1) the amount of water currently assumed to be in the aquifer (and therefore available for agricultural uses) and (2) how the frequencies of droughts affect the recharge rate of the aquifer.

Economic productivity was highest ($\$7.31*10^8$) when the most water was available in the aquifer and lowest ($\$3.02*10^8$) when the least amount was available (there was 40% reduction in economic productivity from scenario 1 to 4) (Figure 3.2).

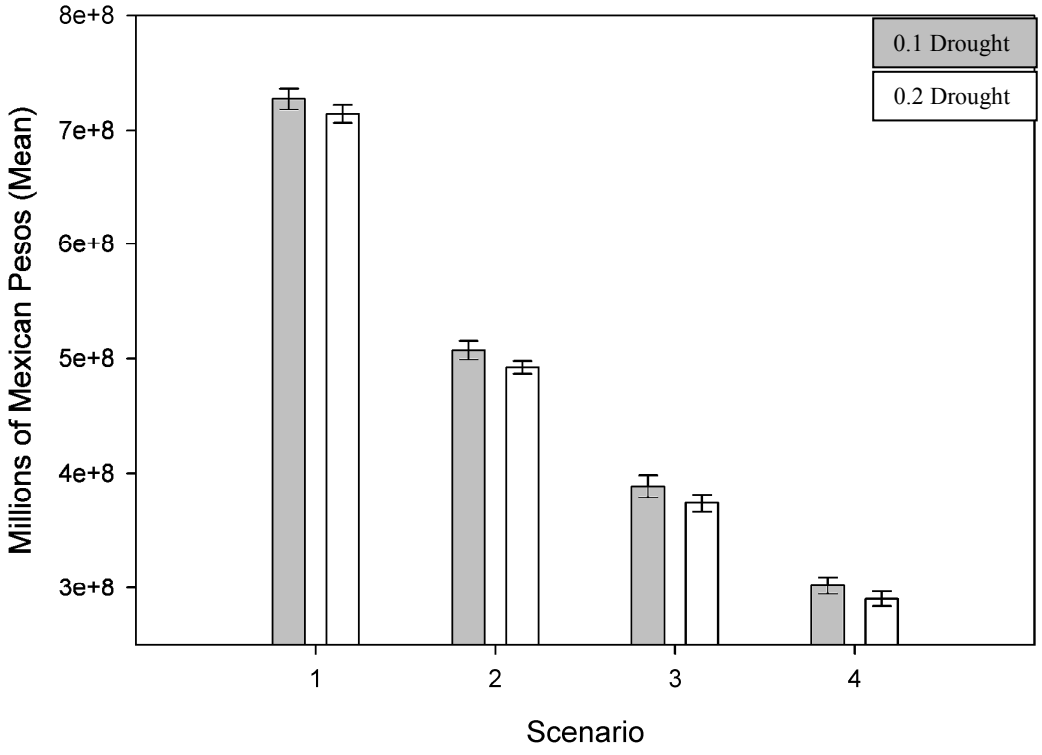


Figure 3.2 Comparisons of Economic Productivity of Four different Initial Estimates of Water in the Aquifer at Drought Probabilities of 0.1 and 0.2 in the Laguna Region.

Considering each drought probability independently, there were statistically significant differences among the scenarios (probability of drought = 0.1: $F_{3,\ 64} = 7925.40$, $p < 0.001$; probability of drought = 0.2: $F_{3,\ 64} = 12097.75$, $p < 0.001$).

For each scenario, increasing the probability of drought significantly decreased economic productivity (Table 3.3).

Table 3.3 Percent Decrease in Economic Productivity Resulting from an Increase in Drought Probability from 0.1 to 0.2. in the Laguna Region. *F-statistic* represents results of one-way ANOVA comparing the effect of different drought probabilities (0.1 and 0.2) on mean economic productivity (in terms of millions of Mexican pesos). Values for mean millions of Mexican pesos for each scenario and drought probability are depicted in Figure 3.2.

Scenario	Percent Decrease (%)	F-statistic$_{2, 16}$	P value
1	1.76	32.32	< 0.001
2	2.91	36.21	< 0.001
3	3.89	21.24	< 0.001
4	3.89	29.29	< 0.001

Further, as the level of water available in the aquifer decreased, the percentage decreased in economic impact of more frequent droughts was greater (Table 3.3).

The presence of hurricanes had a significant effect on the economic productivity of the Laguna Region (Figure 3.3).

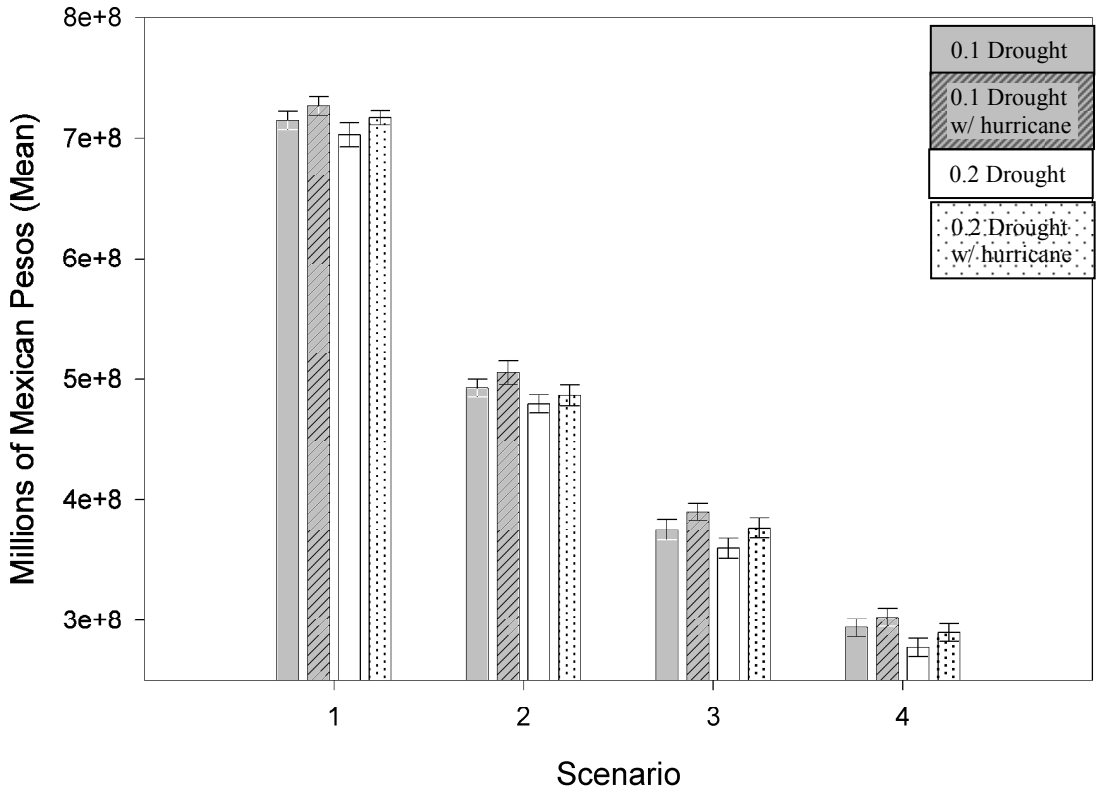


Figure 3.3 Comparisons of Economic Productivity of Four Different Initial Estimates of Water in the Aquifer at Drought Probabilities of 0.1 and 0.2 and with the Presence or Absence of Hurricanes in the Laguna Region.

For each scenario and drought probability combination, the presence of hurricanes significantly increased economic productivity compared to those simulations without hurricanes at the same levels of water availability (Table 3.4).

Table 3.4 Results of ANOVA Comparisons of Mean Millions of Mexican Pesos for Scenarios With and Without Hurricanes in the Laguna Region. (Treating each drought probability separately). *F-statistic* represents results of one-way ANOVA comparing effects of hurricanes to no hurricanes for each scenario.

	Drought 0.1	
Scenario	F-statistic$_{2, 16}$	*P*
1	20.43	<0.001
2	18.72	<0.001
3	29.35	<0.001
4	11.16	0.002
	Drought 0.2	
Scenario	F-statistic$_{2, 16}$	*P*
1	20.1	<0.001
2	4.18	0.04
3	28.23	<0.001
4	22.57	<0.001

For each scenario, economic productivity was largest when drought was lowest and hurricanes were present. The increase in economic productivity due to the presence of hurricanes varied across scenarios, but increased from scenario 1 to 4. The percent increase in economic productivity was similar for each drought probability within each scenario. Scenario 1 had a 2% increase (from $\$7.15*10^8$ to $\$7.27*10^8$) while scenario 4 had a 4% increase ($\$2.94*10^8$ to $\$3.02*10^8$).

The results of these simulations indicated that the main factor controlling economic productivity resulting from agricultural production of the Laguna region is the

estimated amount of water in the aquifer. Four different scenarios were simulated based on current hypothesized values and results indicate that there was a 40% reduction in economic production from the largest to smallest estimated values of water in the aquifer. Results also indicate that droughts and hurricanes can significantly impact economic production – droughts caused a decrease in economic production while hurricanes increased economic production. However, neither droughts nor the presence of hurricanes could significantly "override" the impact that the amount of water in the aquifer had on the economic production of the Laguna region.

CONCLUSIONS

These significant results are based on a sample that was designed to find a mean difference of 2 million pesos. The relative significance of economic production value should then be analyzed under a short and long term impacts' perspective, and based upon specific effects on the society as a whole, the dairy industry, and upon vulnerable economic sectors. The significance might not be meaningful for the society as a whole in the short term, but it certainly affects vulnerable sectors such as the *Ejidos* (communal users) that are directly dependent on the everyday economic production value and on water availability in the short term.

However, the main issue that the simulations do indicate is that the greater the possibilities of a drought, the greater the impacts on economic production. Likewise, the lower the amount of water estimated in the aquifer, the greater the vulnerability to dryer conditions.

Even though this is not a hydrological model *per se*, the effect of hurricanes on the recharge of the aquifer can offer important highlights for future research. The results show a significant effect of hurricanes on economic production, assuming there is an important amount of recharge. This assumption is indeed true when considering economic production, but is not significant in terms of recharge. The mean annual increase of water recharge due to a hurricane event under the best scenario of water availability (scenario 1) and at normal conditions of drought (0.1), is 25% more than the actual estimation (134 Mm^3), but it represents only 10% more of the total actual

extraction rate for all water uses in one year. The amount of water increase in the aquifer after a hurricane event given the actual conditions of water extraction rates, does not represent significantly more water for the aquifers' recharge nor for future water availability. The uncertainty of hurricane events and their short-term impact on the aquifer's water availability, shows hurricanes unreliable for future groundwater supply.

Results show that the amount of water in the aquifer is the embedded variable that determines both the economic production and the vulnerability of the system to dryer conditions. At the present extraction rate and regardless of hurricane events, the less water in the aquifer, the higher the vulnerability to droughts and the higher the economic risk.

These conclusions lead to important ideas for planning policies for semiarid regions that depend heavily on groundwater resources as their main source of economic development. The vulnerability of these systems is more related to actual pumping rates than to levels of water availability. The option of a reduction of vulnerability and uncertainty of the Laguna Region is a limitation of actual pumping rates and, at the same time, urgent investment on research of actual water volume of the Acuifero Principal and predictions of climate change at local scale.

IV. WATER PLANNING UNDER AN UNSUSTAINABLE CONDITION: CHALLENGES FOR THE LAGUNA REGION, MEXICO

SYNOPSIS

The case of the Laguna region offers an example of how the water planning process under conditions of unsustainable water use, gets involved with different social, economic, political and even historical complexities of the different stakeholders' conditions and priorities. After an exploratory study of 30 interviews with stakeholders in the region, four main findings were identified as the conditions in which the planning process takes place: lack of localized data, cognitive communication dissonance, disagreement on problem identification and disagreement on solutions. These conditions demonstrate the challenges of the water planning process, particularly groundwater, but also the challenges for each sector as water vulnerability does not measure equally among them. Vulnerability levels are directly proportional to the temporality, relatedness and spatiality of the water condition of a given type of user. For cities, vulnerability in the short-term is low given that under a crisis, they have the priority over other users, but high if water quality is considered, and as the planning process continues to be unsuccessful, the vulnerability gets higher for all users in the long term. For *ejidatarios,* the vulnerability is the highest because water is conceived also as means of income. For private users, vulnerability is lower since they are already investing in coping strategies for water scarcity. For planners, their vulnerability is more related to the decision-making process and political and economic implications. The region's vulnerability seems to be higher, as water scarcity 'claims' tend to be less related to real water needs. Lack of acknowledgement of the origins of water scarcity, lack of research on planning and management, communication dissonance among stakeholders and, disagreement over priorities, affects and disturbs the planning process and threatens the sustainable possibilities for the region.

THE SETTING

The Laguna region is a closed basin located at the southern edge of the Chihuahua desert in Mexico. It forms the western border of the state of Coahuila and eastern border of the state of Durango. Approximately 1.4 million people live in the area making it the 9th largest population center in Mexico. Just over 80% of the population lives in three cities (Torreon, Gomez Palacio and Lerdo). These cities, plus another four (Mapimi, San Pedro, Matamoros and Francisco I. Madero), operate 70% of water wells and use 96% of municipal water use in the region (Garcia and Guzman, 2007).

Rainfall is limited (250 mm annually) and evaporation rates are extreme (2,500 mm annually) resulting high aridity. In spite of these desert climatic conditions, irrigated agriculture flourishes in the region and is a dominant sector of the economy. Surface water from mountain reservoirs and groundwater supply the agriculture, whereas the cities and industry rely on groundwater. The region faces a number of water related challenges including a declining aquifer, limited opportunities for new supply development, aging infrastructure and improvements in conservation. Perhaps most critical is the depletion of the aquifer that is the primary water source for cities and agriculture.

THE PROBLEM

Data from the Comisión Nacional del Agua (CNA) and from local well logs indicate that the current groundwater pumping rates are resulting in a dramatic decline in the water level of the aquifer and in the region's water supply. Preliminary studies indicate this decline is not sustainable and if continued will lead to reduced water availability and dramatic shifts in the regional economy. Irrigated agriculture, as the dominant sector of the economy, could be significantly impacted as less water will be available for this use.

THE PLANNING AND MANAGEMENT CONTEXT

Over-drafting of limited recharge aquifers throughout Mexico resulted in significant changes, namely, national legal reforms governing water rights, hydrologic basin planning and management. These reforms established a federal permit system for

groundwater pumping and allowed for the voluntary transfer of pumping permits. As a result, some groundwater rights trades have begun between industry and agriculture (Bruns *et al.,* 2004). In addition to water rights reforms, Mexico enacted institutional reforms on water planning and management. Over the last two decades these reforms followed a concept of Integrated Water Resource Management promoted by a number of international organizations (Biswas *et al.,* 2005). These reforms were strongly linked to major shifts by the national government toward pro-market policies enabling water users and stakeholders a greater role in water allocation, planning and management (Bruns *et al.,* 2004). Mexico's reforms are predicated on (1) establishing federal institutions to administer the water laws; (2) defining the role of the federal and state governments in water administration (3) integrating surface and groundwater planning and management; (4) establishing and administering a federal water rights system and authorizing water transfers; (5) decentralizing federal planning functions linked to 13 hydrologic regions; (6) involving water users, stakeholders and citizens in planning and management; (7) reducing subsidies to agriculture and (8) reducing the overpumping of aquifers.

The Ley Nacional de Agua (LNA), enacted in 1992 reaffirmed a federal water rights systems and established federal and state and basin water management agencies. The CNA is responsible for water policy, water rights, planning, water supply, irrigation and disaster planning. The Ministry of Environment and Natural Resources (SEMARNAT) has the responsibility for managing CNA. State water commissions (SWA's) do have some authority for managing water public water supply and public water treatment systems. Basin Authorities (BA's) are regional offices of the CNA established to work at a regional level on planning and policy development.

The 2004 amendments to the LNA transferred some managerial and planning responsibilities from the CNA to regional basin agencies in order to decentralize some of the planning, research and management responsibility from Mexico City to different regions of the country. However, the final authority for planning and management still resides with the federal government (Scott and Banister, 2007).

The LNA also changed the method for allocation of ground water throughout Mexico. It restricts the granting of new water rights on fully appropriated basins. This change is expected to create a market for water rights (National Research Council, 1995). Experience in Mexico indicates that the relevant time scale for reform may be best measured not in years but in decades (Garduño, 2001).

This chapter, in part, examines the understanding of water users and stakeholders in the Laguna region regarding their role in water planning and management. It is an exploratory investigation of water users' beliefs regarding water scarcity and of their options for addressing scarcity. Also, a vulnerability assessment given their beliefs, options and priorities related to water scarcity is addressed. Results from this research could help with the design of a stakeholder framework for planning and management of the region's water resources. It must be noted that the Laguna region is located in one of the 13 regional hydrologic units experiencing aquifer over-drafting.

MATERIALS AND METHODS

Data for this part of the research were obtained from 30 targeted interviews with representative of the different sectors of water users, managers, officials and experts at city, state and national level in the region (See Table 4.1). Five groups were identified: federal and state water managers, cities and urban officials, private users (industries and private irrigators), communal users (small irrigators or *ejidatarios*) and academics or experts.

Table 4.1 Distribution of Interviews among Categories and Sectors in the Laguna Region.

Categories	**Sectors**	**No. of Interviews**
Federal	Coahuila, Durango	2
State	Coahuila, Durango	2
Cities	Torreon Mapimi Gomez Palacio (2) Fco I Madero Matamoros Lerdo	7
Water users	Industry	2
	Private farmers	3
	Ejidos	3
	Urban (Torreon, Gomez Palacio)	2
Academics	Private and Public	9

The interviews were taped and transcribed in order to compare and contrast interviewee responses. The interviews began with open ended questions. These questions were designed to encourage a full, meaningful answer using the subject's own knowledge and/or feelings. It is the opposite of a *closed-ended question*, which encourages a short or single-word answer. Open-ended questions also tend to be more objective and less leading than closed-ended questions (Dick, 1998). The initial question ("Based on your experience, how would you define-characterize the condition of the water resources in the Laguna Region?") was followed by a set of questions that were generally intended to identify three important aspects: why do they say there is a problem with water (whatever the problem is)?; what is or are the problems they see?; is there any possibility for change towards sustainability?; and, what do they recommend should be done to improve the actual conditions?

Interview data was used to developed theories of stakeholder attitudes, opinions and preferences regarding aquifer depletion, water scarcity, user vulnerability, and prospective scenarios. A grounded theory approach was used to analyze the interview responses (Dick, 1998; Dey, 1999; Glaser, 2002). This approach uses the inductive

method to generate concepts, categories and propositions from a constant analysis, comparisons and development of theoretical relationships (Glaser and Strauss, 1967). Grounded theory is not generated *a priori* and then subsequently tested, since there were no hypotheses tested. Rather, it is inductively derived from the study of the phenomenon representing water scarcity. That is, discovered, developed, and provisionally verified through systematic data collection and analysis of data related to that issue. For this methodology, one does not begin with a theory, and then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge (Strauss and Corbin, 1990).

Five patterns of responses emerged from the interviews that may provide guidance to federal officials on implementation of a stakeholder based the planning process. As a result of the reforms of the 1990's, Mexico is shifting from a supply enhancement plan prepared by consultants, to a stakeholders' based process. Among the factors driving this are high construction costs, limited new supplies, imperatives for greater efficiency through conservation, and increased stakeholders involvement in decision-making. The World Bank, which provided funding for some of Mexico's water planning and infrastructure projects, has adopted a stakeholder involvement planning framework emphasizing "decentralized management and delivery systems." This framework is used by the Bank to guide their funding decisions in regions where significant water scarcity problems exist (World Bank, 1993). Traditional planning and management approaches relied on experts to prepare plans. Nowadays, the paradigm of dam building and increased aquifer pumping, while still entrenched in national water planning, is under greater scrutiny. Texas recently transitioned to the new planning paradigm, focusing on decentralization management and a stakeholder-based planning was recently adopted (Kaiser, 1996; Silvy, 2000).

Transitioning to this new approach in Mexico will not be accomplished in a year-- it may take a decade. Texas, for example, is transitioning to a stakeholder based decentralized approach focusing on efficiency improvements, conservation, demand

management, water transfers. The state is in the second decade of process implementation.

Predicates for this decentralized citizen based approach include stakeholder: (1) involvement in research and data collection; (2) acceptance of data; (3) involvement in educational efforts; (4) input on project decisions; and (5) trust in the governmental institutions (Silvy, 2001). The items of concern expressed by stakeholders in this study have a direct bearing on these predicates and should be considered by federal policy makers.

RESULTS

Lack of Localized Data

Statistics on water availability and consumption trends are mostly regional or national in scale. There is little localized data for the Laguna that can form the basis for planning. This concern was expressed in various forms by the stakeholders who opined that the lack of localized hydrologic data and its effects on the community have been underestimated and neglected when trying to identify the main issues and causes concerning water scarcity. The following illustrative statement captures this sentiment.

> There is no consensus among scientists of what the problem is to start with, not to say anything on the strategies we should adopt to solve it; they don't even agree on their own measurements and they do not offer confident scenarios of actual and future water use (Federal Official, 2009).

This issue was also expressed by local officials and water users in the region.

> The Comisión Nacional del Agua cannot afford to attend, monitor, control, and enforce regulations…they have 11 inspectors for 2,000 wells, do you think they have time for research?"…the office in Torreon cannot do much but to expect that we agree on what we should do (State Official and City Official, 2009).

For cities, this gap of localized data directly affects their infrastructure funding capacity. Consequently they have to rely on regional or nationwide data from federal and state governments with all the limitations and local risks that come with it.

> We are operating fine in the city, we will have water for the next 5 years….though we don't know what is the annual water demand (City Official, 2009).

> We don't know for sure, but approximately 35% of the people is paying their bills (City Official, 2009).

> We don't have enough funding for that, but I know that the Water Commission is doing *something* on water treatment, we are waiting for their results…so we hope that is going to help us (State Official, 2009).

In the case of private agricultural users, the data they use comes either from their own research primarily focused on their private objectives and planning purposes, or from private academic institutions hired to comply with their private interests of investment on efficient irrigation techniques and crop seeding.

> We have done our own research on water availability, though it has been only during extraordinary dryer conditions (Industry and Private Farmer, 2009).

Another agricultural user has acquired specialized equipment in order to provide accurate data.

> I have my own meteorological station so I do not have to rely on federal numbers, you never know if they will be always available, and sometimes they do not offer what I need to operate on a daily basis…Everybody says the aquifer is been overexploited, but all my wells are working well since 1980's, I do not know where are they getting their numbers…actual research is just not enough to prove this fact (Private Farmer, 2009).

In the case of *Ejidos* or communal users, water availability data forming the basis for the crop planting schedules is derived from annual reports of how much water is in storage

mountain reservoirs. They do not have access to data or ongoing research programs. Expressions of their frustration are epitomized in the following statement referring to the federal managers of these reservoirs:

> They are stubborn…we keep telling them that it has been proven that this irrigation method works much better and saves more water, but they don't care, they keep using the same old techniques (Irrigation District, 2009).

The lack of institutions that support research education and technical expertise to *ejidatarios* and their genuine lack of interest on the matter, has lead to a vicious cycle in which water resources continue to be degraded.

> The agricultural user doesn't care about the aquifer as long as they have their share and as long as the data they rely on is the storage level in the dam… agriculture users get encouraged and demand for more water when there *seems* to be more water available, regardless of the hydrological conditions and water overexploitation (Irrigation District, 2009).

Some very knowledgeable and recognized scientists in the region, actually defended the lack of localized data regarding the actual reserves of water saying that:

> It doesn´t matter how much water there is in the aquifer…we know that water levels are decreasing and that should be enough to recognize that there is a problem with overexploitation, and the authorities are acting passively towards this fact", and this point was shared among other scientists (Academic, 2009).

> Water users do not need as much information as possible to make decisions and face risks; they can rely on past history (State Official, 2009).

Based on past practices this statement might be true, but this is not what water users and other stakeholder need to make decisions.

Researcher Comment

The lack of data not only affects the understanding of the problem at every level of authority, but creates a vicious cycle of dependency to higher authorities for decision-

making, promoting a passive attitude towards water threats, problem solving and water planning. The literature on water-scarcity planning research is practically nonexistent in the region. Literature is limited to hydrological studies in the region and some historical analysis of the absence of groundwater regulation (Whiteford and Meville, 2001; CNA 2000, 2004; Navarrete and Melville, 2004; Hernandez, 2005).

The studies related to levels of extraction in the region, come from a broader perspective that includes all northeastern region and the smallest level of analysis includes two states (Coahuila and Durango). So, information on water use, quality, and policy development over groundwater issues, has been mainly controlled under national standards instead of regional standards. The reports of the CNA from 1994 to 2002 offer mainly regional analysis and they do not offer technical or critical information on specific cases, except for an assessment of annual water availability in the Acuifero Principal (CNA, 2002). From this perspective, what is known about the overexploitation of the aquifer is very general and it only gets specific when it comes to dairy and meat production, which are generally related to the economic value of the region and its productivity importance for the northern part of the country, but not necessarily related to the water stress condition in the region (Plana, 1996; Salas, 2002; Martinez *et al.,* 2003).

The work by Whiteford and Melville (2001) is one of the few that touches the challenge of water scarcity on growing urban centers in Mexico and the changing role of states and cities to be more proactive in the development of new regulations to protect water resources. The text by R. Ahlers *et al.* (1999) deals specifically with the Laguna Region and makes an analysis on discrepancies between national level policy and local implementation, where market 'informalities' came into place and water allocation under neoliberal logics locates the problem of policy development in a secondary priority place.

There are also national papers that refer to the history of water regulation on the Laguna region (Navarrete and Melville, 2004; Hernandez, 2005), which deal with the historical relationship between groundwater regulation, economic development and

national events, and give a general overview on how the policy development had to be adapted or restrained by the economic priorities or the predominant interests of the region. The literature that addresses the different subjects related to the overexploitation of the Laguna aquifer is mainly related to the subsequent economic activities that are sustained by groundwater extraction: the diary and meat industry in the region and their socioeconomic impact on the region (Martinez *et al*., 2003; Corona 2005; Garcia and Guzman, 2007).

Interestingly, there is more analysis on the fact that there is no data, than on the issue that there is no interest in dealing with planning policy issues. There are no sustainable models considered or vulnerability assessments in the region. Moreover, there are only few studies on the efficiency of irrigation systems in the region, and subsequently, there is no alternative analysis of possible scenarios of a different policy strategy that can possibly ameliorate the water stress condition in the aquifer (CNA 1986, 2002, 2004; Rochefort and Cobb, 1994; Cruz and Levine, 1998; Hernandez, 2004; Hernandez, 2006; Guzman *et al.*, 2006; Garcia *et al.,* 2006). "We need a change in culture, values and attitudes…we need to enforce environmental education since junior school to our children so we can guarantee a more proactive attitude towards the research in the future" (Academic, 2009).

Cognitive Communication Dissonance

Cognitive dissonance results when stakeholders have contradictory attitudes, beliefs and behaviors. Dissonance in this context occurs when logical inconsistencies in behaviors become apparent, straining communication channels. This pattern is clearly evident among the stakeholders in the Laguna region.

> They are political appointments (federal water managers); they are passive and soft with large waters users because of their political and economical implications (Academic, 2009).

At the same time, there is a lack of communication and agreements that neither sector consider important to improve, because in any case they do not trust each other.

> How do you explain than from one day to another, there are 1,000 new wells operation in the region? ...It's a mess what the federal government has done in the region (Private Farmer, 2009).

> We just do not trust their numbers…their methodologies are not well understood (Private Farmer, 2009).

And some even went further saying…

> But we do not trust either what the National Commission is saying…because the way they do measurements, monitoring and follow ups are not trustworthy…some day they measure here and the other they measure there (Private Farmer, 2009).

Even among federal water related agencies, the communication flows are just assumed to be efficient and proactive, but there seems to be not only lack of feedback, but lack of interest in whatever the feedback is. The following is a transcription of a short dialogue with a federal official that is a complete portrait:

Question: What is your opinion on the overexploitation of the aquifer?

> I don't think there is overexploitation or mining in the aquifer. I trust the Comisión Nacional del Agua.

Question: Are you aware that the Comisión Nacional del Agua has recognized a condition of overexploitation in the aquifer?

> Then, I'm with them (Federal Official, 2009).

As a State Official argued:

> We are not connected to Torreon sewage infrastructure because of parties' political differences between the State and the city, and the city is growing so rapidly that now it seems absurd to have two different systems located in the same area; we are being inefficient, but they don't like each other (State Official, 2009).

In the same way, urban and agricultural users' communication flows tend to be highly noisy and disturbed by economic and social differences, especially during extraordinary dry seasons, as it has been said.

> We fell under attack the whole time; they make us feel as we were the bad guys…but we are willing to communicate and make decisions…just let us know and prove your points (Private Farmer, 2009).

The communication disturbance highlighted in the feedback of the scientific community, does not only relate to the eroded institutional communication flows or the lack of trust among parties involved, but it has to do also with a passive attitude and lack of interest of society itself in the water issues.

> It is only until recently, when the arsenic problem arise, that we are seeing some social movement around the water issues, but up until then, the society has been silent and does not seem interested (City Official, 2009).

> The Laguna society is simply passive and ignorant…the information is there! It is available everyday in the newspapers, but they just don't respond (City Official, 2009).

However, on the other side, there were also those who attribute this social passiveness to governmental institutional failure in education, legal compliance and public service.

> The government has created these informal legal schemes in which people have found their way (Academic, 2009).

> If they have to pay their water bills, they just look for their community leader to pressure the authority, they don't have to care if water is been wasted or not (Academic and City Official, 2009).

This reality not only affects the water planning process and with that, the sustainability of the region, but the development of research itself, the improvement of knowledge of

natural resources in the area and it contributes to the passive attitude of society towards environmental threats.

As an example, Figure 4.1 shows the managers' or planners' sector, which receives direct information from urban and domestic users on a daily institutional contact with users and media coverage. However, the feedback that users received appears to be disturbed by noisy information flows coming from the scientific community that attacks and diminishes managers' decisions (regardless of the validity of their arguments), and some economic pressure from important private agricultural users.

Researcher Comment

As a result of cognitive dissonance between stakeholders, there is a discrepancy between what academics think planners should do, and what academics should investigate according to managers and planners. This gap has eroded their communication, confidence and collaboration, especially because the scientific community is originally from the region and federal authorities are appointed directly from Mexico City; their communication does not follow the same patterns. In the same way, feedback does not affect or attend the same priorities.

Figure 4.1 illustrates communication flow between different sectors in which flows and feedback among different sectors can be direct, indirect and disturbed depending on the "noise". Noise can be interpreted as the lack of communication, distrust, obstacles to feedback, low confidence, low level of scientific rigor, and political differences and interests. This model represents the conclusions driven by the perspectives, experiences and conditions of the interviewees, and also to the literature reviewed. As it is shown, the domestic-urban sector has a free noise relationship between state-federal and the academic sectors. Their needs and priorities to federal and state authorities and to the scientific community and the type of issues generally communicated are easily processed given two special conditions: their issues tend to be soft and have low impact effects on the water use model in the region. Infrastructure improvements, economic efficiency and even water treatment are positive issues recognized and shared by the rest of stakeholders. However, when it comes to

communication with the private and communal sector, then communication and feedback becomes highly noisy given the negative connotation of the agricultural sector as the "bad guys" or the responsible sector for the overexploitation of the aquifer. Again, urban users do not consider themselves responsible for the actual condition and they do not relay or consider agricultural needs and knowhow knowledge when it comes to planning for conservation, water savings and efficiency.

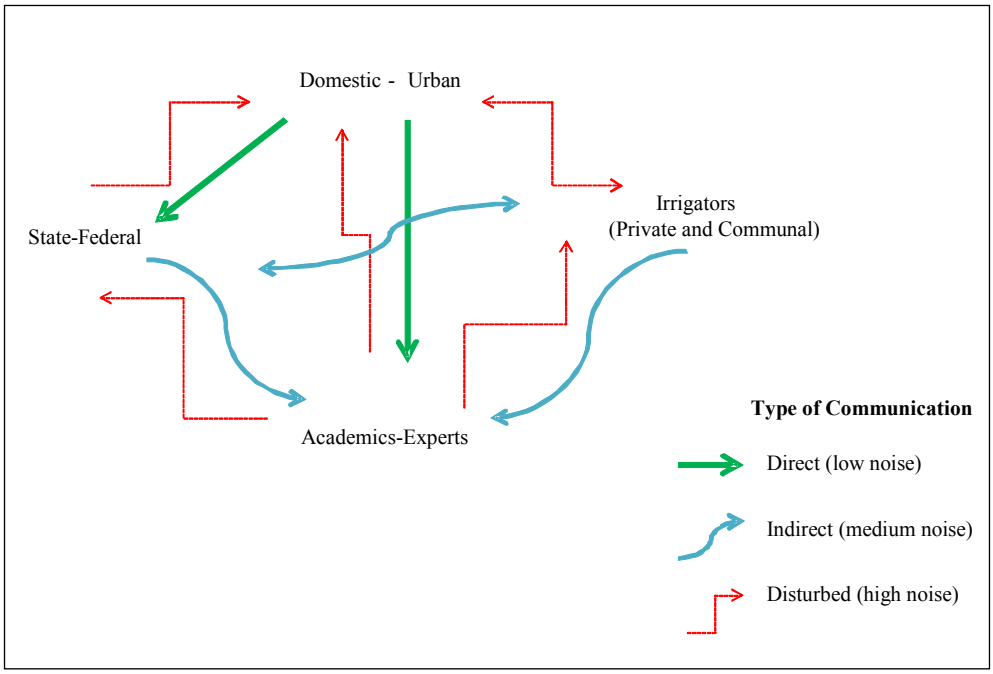


Figure 4.1 Communication Flow Between Sectors in the Laguna Region.

In the case of state and federal sector, the communication flows from them to irrigators and academics tend to be indirect with medium levels of noise mostly related to lack of reliable information for irrigators and lack of communication and trust with the academic sector. As public designated authorities, they need to inform the society of the conditions and actions taken to overcome the water issues, specifically the overexploitation, but the perception or the feedback of academics is generally characterized as passive, poorly informed and unreliable. High impact decisions are expected and claimed by urban and academic sectors, but the feedback returns disturbed

given economic, social and political implications. As it has been mentioned before, the private sector uses whatever is useful for their business sustainability either for the public or the academic sector exposing their selected needs and issues to state and the academic sector, however, the positive feedback is not completed since the academic sector and urban sectors pressure irrigators to stop pumping water and attack them as the guilty sector, highly disturbing the trust and the possibilities to construct breaches in the long term. The only medium noise relationship in the model is the one between state and federal sector and the irrigators, given that both recognize and depend on similar economical and political conditions.

Interestingly from this simple model, it is indeed the academic sector which has more disturbances on their feedback to the other sectors. The tendency to isolate and restrain the scientific knowledge to the academic community without considering practical needs, social clustering, neglecting construction of bridges between science and policy development and disinterest in the planning "process" as a fundamental key for the decision-making process is not uncommon around the world (Greenberg, 2001).

This disaggregation in which science has the main responsibility as providers of confidence and risk, it's a constant in the science-policy relationship model in Mexico, and the Laguna region does not seem to be the exception. The vulnerability risk to regions in which the scientific community does not adequately and efficiently communicate with the rest of the sectors has proven to be highly risky for the sustainability of the region; their share of the responsibility is not, by any means, negligible (Wisner *et al*., 1994).

Lack of data and research, distrust on available data and disturbance in the communication flows, have lead the regions' water planning environment into a passive, informal and distrustful steady-state environment in which communication flows get disturbed and neglected based not only on how, what and who communicates, but also on who listens, what listens and how is it interpreted. The interpretation is based primarily on their particular economical, political and social experience; and, secondarily, on water knowledge and expertise.

Disagreement on Problem Identification

Though the lack of research and communication disturbance define the mechanics of water scarcity perceptions among users, it is true that the actual mining condition of the aquifer is well known among stakeholders in the region. However, the threatening condition that this hydrological fact could represent in the short or long term for each of the water users' categories is not perceived equally, because they are not equally affected by the water issues involved and their understanding is limited to the boundaries of their specific priorities.

Cities and urban users, private and communal agricultural users, city, state and federal officials and academics as well, defined the condition of the water resources in the region as critical. They characterized the condition with adjectives such as: "dangerous", "critical", "problematic", "threatened", "unsustainable", "chaotic", "towards collapse", "on risk", "negligent and unattended", "overexploited", "inefficiently used". However, when they were asked if they suffered from water scarcity to fulfill their needs, their answers varied from:

> We have enough water, our problem is the efficiency and people are not paying the price (not the cost)…We have enough water for the cities, but agriculture's large use is affecting the quality of our water (City Officials, 2009).

> The problem is not that we do not have enough water, but cities are badly planned and disorganized so we do not have the capability to attend to everybody's water needs…People say we are running out of water because when they open their taps, there is no water flowing, but that is another problem (City Official, 2009).

For cities, the issues regarding a mining condition of the aquifer or an imminent water scarcity crisis in the near future as the Comisión Nacional del Agua has estimated, doesn't appear threatening for their water utilities; rather it is the technical and economic efficiency of water infrastructure and water quality issues their main concern, neglecting their direct relationship and responsibility to the aquifer's sustainability.

> We only use a small percentage of groundwater (not even 2%); the irrigators are the ones that use most of it…There is where the problem is (City Official, 2009).

> Our problem is to deal with political leaders that use water to sabotage communities' compliance and we depend on the State resources to fulfill our financial needs, because people here are not paying their already subsidized bills and we can't force them to do it (City Official, 2009).

Apparently, the fact that cities use a small amount of groundwater compared to that used for agriculture, liberates them from the problem of the aquifer's mining condition and it constitutes somebody else's responsibility.

> We have enough water for the next five years; we only need to improve our efficiency and water treatment (Cities Officials, 2009).

The other problem identified by the cities is water quality. In 1990 it was reported that 400,000 people that lived in rural areas were exposed to high arsenic water concentrations (above the limit accepted by the World Health Organization of 10 micrograms per liter) and as for today, the majority of the urban population in the Laguna consumes water with arsenic concentrations above 10 micrograms per liter (the national norm establishes a limit of 25 micrograms per liter) (Ramirez, 2008). However, the same reasoning applies. The relationship between water quality and water quantity is not assumed as to be directly related to the mining of the aquifer, and if it is, agricultural use which is federally regulated, is responsible for attending the issue.

> If the federal government decided to reduce the national norm to 10 micrograms per liter today, half the wells in the region would have to be closed down…But they can't do that, we need the water so we are working on treatment techniques (City and State Officials, 2009).

For academics, however, water quality does not constitute the main problem. Research to remove arsenic in the region started in the 1960's, but only recently have sensitive health issues been elevated to the regional agenda. Technology to remove arsenic is

already existent (membranes techniques), accessible and economically efficient (less than one peso per cubic meter) (Ramirez, 2008).

> The problem is already being considered and it is hoped to be solved in the near future (Academics, 2009).

The main issue identified by academics is the lack of enforcement of the legal regime and the passivity of federal authorities to address the issue of the aquifer's mining condition. It has been stated that lack of leadership and the failure in negotiation processes among different sectors has driven the region to an impasse in planning process and to a subsequent unsustainable water management (Hernandez A., 2005; Hernandez, 2008; Academic and Federal Official). However, it is also evident that nobody wants to take responsibility of the costs that leadership might bring.

> Who is going to take the bell from the cat if we are all mice? (Academic, 2009).

The political and economic implications of any federal decision that could reduce groundwater extractions by large water users (private irrigators), have been historically risky and have limited the role of federal officers as merely observers and mediators between economic and political regional stakeholders (Academics, 2009).
Likewise, a generalized perception among academics was the argument that the water legal framework does not offer instruments to fulfill the enforcement of federal regulations. They do agree on the matter that the legal frame could be enough to support a sustainable approach in the region, but the instrumentation, financial, technical, institutional and human expertise are poorly endorsed by actual regulations, offering a wide open space for irregularities, informal practices, abuse and impunity (Hernandez, 2004; Academics, 2009).

> Our legal framework is enough to look forward a sustainable approach, but we don't have the institutional willingness and instruments to operate it and enforce it (Academics, 2009).

Another pointed issue is the argument that is not enough to promote efficiency regulations on irrigation techniques, since there are no limits to irrigated land, as some experts expressed:

> Even if we were hundred percent efficient, that would not be enough to overcome the degradation of the aquifer, and besides, it wouldn't be economically efficient (Academics and Private Industry, 2009).

> Nevertheless, those water savings are not traduced on reduction of their extraction rates because there stills no limits to the agricultural frontier (Academic, 2009).

For federal and state managers, however, the main problem behind the mining of the aquifer is the culture of the *laguneros* and the fact that water users do not agree on what should be done and who should start changing. They do not consider themselves as responsible for the actual mining condition, but regional stakeholders' incapacity to negotiate and address their own issues. The actual economic development model of the region has been constructed under logic of extensive and intensive groundwater use since the 1940's, and as a State official pointed out:

> I don't understand why they insist on having their cows and their forage in there knowing the actual condition; somebody needs to do an anthropologic study on the behavior and thoughts of the *laguneros* (State Official, 2009).

> The change will not come from the government, the society has to pressure and call for their own changes, otherwise nothing will change…and today's society still seems indifferent to the situation (City Official, 2009).

Another problem identified by planners is that even though the present extraction rate of groundwater is recognized by every sector as unsustainable, there is also an acknowledgment of high resistance to dramatic changes at the present model of water use in the region.

> The chaos and social pressure that can be expected if any dramatic change is made to the actual economic model, is a cost we are not willing to take (Federal Official, 2009).

> Employment for rural population relies practically on agriculture, and regional wealth related to cattle and milk production is too high to even enforce the actual regulatory scheme -at least to comply with the concessions registered by the Comisión Nacional del Agua (Federal Official, 2009).

State and federal planners have decided to wait until water users agree on what needs to be done, assuming then an expectator role.

> There is not even an agreement yet among parties in what should be done, so there is no need to risk that much if we don't have a better alternative (Federal and State Officials, 2009).

For private and communal irrigators, different problems arise and some are interrelated. Private irrigators pointed out the problem of insufficient and trustful data, specifically on groundwater availability and quality that offers the perfect –and yet valid- reason to keep pumping water at the same and even greater rates.

> Even some people say that if we reduce the pumping extraction, there could be higher arsenic concentrations because of the geology of the region, I don't know, so meanwhile I have to keep going (Private Farmer, 2009).

Private irrigators also expressed their concerns of feeling unfairly attacked, especially under dryer conditions when other users condemned their high pumping rates, pressuring them for investment on water efficiency and irrigation techniques.

> Pressure and attacks related to water scarcity come and go as rain comes and goes (Private Farmer, 2009).

The effect of a hurricane seems to decrease the social pressure over large users, and then it rises again when droughts or dryer conditions threaten the region, as a private industry official said:

> We feel pressured every time the dam is not full or during droughts…And our vulnerability increases and decreases with that cycle too (Private Industry, 2009).

As for today, the Lazaro Cardenas dam has reached 90% storage capacity, which means that actual social pressure on large agricultural users is reduced. However, it is important to mention that groundwater use seems to be negligent of hurricane effects on recharge according to previous results, thus this could mean that social pressure tends to be directly related to surface water (dam storage), and not to groundwater which keeps being pumped regardless of the hydrological cycle. This might be one explanation of why, acknowledging the overexploitation of the aquifer, it doesn't seem to be a real concern in the society; surface water dominates public attention and the political agenda. If we see water, we believe there is water (IFIAS, 1988; Plana 1996; Martinez *et al.,* 2003; Academic, 2009).

Another problem identified by private farmers is *ejidatarios* lack of efficiency in their irrigation techniques and they tend to have political interested-based claims of water.

> Every private ranch owns at least five water rights -(the amounts are variable)- but we rent at least half of them from *ejidatarios* during the season so we can irrigate more land…But look at my land –and points out his crops- I invest thousands of pesos in irrigation techniques and I am not wasting a drop of water…I am using less water per unit of crop…*Ejidatarios* keep using old techniques and are only interested on getting their income, not on growing any business or on water savings (Private Farmers, 2009).

> It is a hard time to deal with *ejidatarios*, they just follow whatever the leaders' interests are and they might not be even related to water needs (Private Farmer, 2009).

On the other hand, communal users accuse private irrigators of water rights concentration creating a dependency condition. *Ejidos* lease and sell their water rights (mainly to private farmers) as means of income, thus raising their level of vulnerability to water scarcity. The water problem they identify has to do with social and economic needs, not with overexploitation of the aquifer. Though the cycle of pressure identified by private farmers goes up and down with wetter or dryer conditions, this does not mean that water demand behaves accordingly. This situation was expressed by some *ejidatarios*:

> When we have droughts we suffer and claim for water, and when there is a hurricane we don't suffer, but we keep claiming for even more water! (Irrigation District, 2009).

> When the dam is full, *ejidatarios* demand more water for two reasons: they can sell more water rights and earn more money; or, they can irrigate more -the same amount of land though- thinking they can actually harvest more with more water …That is a lie! They do not need more water, they can actually harvest more with less water if they change their irrigation techniques, but they are stubborn and manipulated by community leaders and they use their water rights as their annual income (Irrigation District, 2009).

These differences among perceptions of water issues between *ejidatarios* and private farmers tend to be underestimated and neglected when addressing alternatives to overcome the predicted water scarcity. Both, private and communal irrigators tend to accuse each other of their respective water use, and at the same time they justify and excuse their responsibility either through investment on irrigation techniques or as a means for survival. Though both excuses are valid for their interests and priorities, neither respond to the real need to reduce the aquifers' withdrawals.

> It is not that we are running out of water; we have lots of water and more than enough. What we don't have is money and employment for *ejidatarios*; and we don't have limits to the rich, they just keep growing and growing using as much water as they can because nothing limits them (Irrigation District, 2009).

What communal agricultural users consider as water scarcity, simply reflects an historical economic condition of poverty, unemployment and abandonment of their productive activity. What private farmers and ranchers consider as water scarcity is social pressure against their water uses that force them to invest in conservation and modern irrigation techniques.

An underlying problem that was identified as a commonality among stakeholders representing cities, private users, communal users and academics, was the direct relationship between the water planning process or the lack of a water planning, and the actual overexploited water condition.

> Question: Would it be fair to say that the lack of planning strategies, have led us to the actual risky condition?
>
> I absolutely believe that the actual condition of water scarcity was driven by our incapacity for planning, not by water availability (Cities Officials, Academics, Irrigation Districts, Private Irrigators, 2009).
>
> We have lots of water, but we have been incapable of managing it (Academic, 2009).
>
> We are making a mess of our privileged resources (Academic, 2009).

Researcher Comment

It is important to recall that these findings in the Laguna region are not globally unique. It has been recognized worldwide that in many countries water scarcity has been the result of public policies that have promoted the excessive water use through subsidies and price dumping (Oudshoorn, 1997; UNDP Report, 2006). For example, it is possible that a country such as Uzbekistan with a comfortable water availability of more than 2000 m3/cap. experiences the actual withdrawal amount of more than 50% due to inadequate management, and this can be easily classified as a scarce situation (Oudshoorn, 1997).

The underlying effect of insufficient or unreliable available data has greatly affected the planning process. Lack of reliable data is used as excuse or even a valid reason to maintain the actual model of economic development and extraction rate in the region. This reality adds obstacles to the already deconstructive planning process. At this point the quote of journalist Jose Mena makes sense:

> Everybody knows we are running out of water, but everybody knows we can´t do anything about it. (Mena, 2008)

However, this statement could be very well adapted to fit the results of this paper so far by rephrasing it as: Everybody thinks we are running out of water, but nobody is willing to understand what the real problem is.

Disagreement on the Solutions

Because there is an important lack of data and basic research on the hydrological conditions of the region, and above that, there is distrust on the available data given the eroded communication feedbacks among categories, it is not surprising that they do not identify the same problems of water related issues and furthermore, it is logical they would not agree on what needs to be done to overcome the actual unsustainable scenario.

The solutions offered by the scientific community are varied. There were some extreme such as the relocation of the basin milk, some of high impact such as to enforce the actual regulatory scheme by reducing the pumping rates to the amount of recharge (which represents approximately 50% less, according to official estimations), and some moderated that pretend to gradually reduce the amount of water used by irrigators through crop conversion and improved irrigation techniques. The similarity among academics, private users, cities and communal users is that they all call for federal and state involvement and effective enforcement on any of the solutions adopted. They also agree that solutions should encourage the reduction of groundwater use for irrigation.

> We need the active participation of federal and state authorities to solve this and put limits to large water users, otherwise, no real change can be expected (Academic, 2009).

> It is true that we need to solve the arsenic problem, but that will not help the overexploitation of the aquifer…we need to stop drilling (Academic, 2009).

> We need a more decisive role of federal and state authorities in whatever the solutions are; otherwise, no matter what the agreements are if there are not going to be enforcement mechanisms (Private Farmer, 2009).

> We understand we can't keep going drilling, that is why we are investing not only of better irrigation techniques, but on different crops besides forages, but the federal government needs to do their part (Private Farmers, 2009).

For federal and state officials on the other hand, the solutions must come from negotiation among users. Unfortunately, their perceptions towards attaining sustainable solutions are not optimistic. There is a general recognition that if solutions are finally agreed upon, they might not be enough to effectively change the actual degradation course.

> I think we are starting to see some improvement on agreements between users, though the needed solutions will not be attained soon enough for the sustainability of the aquifer (Federal Official, 2009).

> I hope that people react and become involved and aware of the dangerous condition we are facing towards the future, I am not sure if we are going to make it (City Official, 2009).

This view was also shared by private users and communal users, but even with more extreme perspective:

> The problem is not that we are ignoring that change is needed; is the velocity that is going to take to reach that change (Private Users and Irrigation Districts, 2009).

It seems that political, economic and social implications for more efficient solutions only allow small steps at a time.

> We just can't change our economic and legal model one day to the other, it is too costly. What large water users are betting is to wait until wells get dry and then they will either change or move out (State Official, 2009).

This extreme solution was not uncommon among the private sector…

> The only possible solution for us is to eventually move out, because if we try to be 100% efficient on water use at this point, it would be economically inefficient (Private Industry, 2009).

> We wouldn't like to go, but we are prepared to do so (Private Industry, 2009).

> I already bought land far away from here for forage production, so I can depend less on the Laguna water resources for my cattle, just in case (Private Farmer, 2009).

Hypothetically, even if this scenario was considered to provide the solution for a dramatic change in the region, the problem of water scarcity will still remain for cities, small farmers and *ejidatarios*. For the cities, given the passivity and unfeasibility of real change in the near future, their solutions are focused on looking for new sources of water.

> The treatment of Nazas river for domestic and urban use will be definitively a great solution (Cities Officials and State Official, 2009).

> We are now exploring the area of Jimulco for future drillings (Cities Officials, 2009).

Likewise, water treatment for arsenic removal is the first priority on the list of solutions to the water issues identified by cities. Again, the short-term solutions rule the cities agenda.

> The problem we have is water quality, so our solutions must go to that direction…and we are in fact already improving our water treatment and developing our own technology for arsenic removal (City Official, 2009).

Meanwhile, academics keep clamoring for more long-term solutions, which encourage looking for solutions that encourage the reduction of the actual pumping rate.

> It's simple, at grater pumping levels, greater arsenic concentrations…we need to stop drilling at these levels (300 meters) if we want to improve our quality (Academic, 2009).

> I think the arsenic problem will be solved soon, but the main issue regarding the mining of the aquifer will continue (Academic, 2009).

For *ejidatarios* on the other hand, their options have been already reduced to selling and leasing their land and water rights. Likewise, urban growth has affected land use for agriculture reducing their possibilities of going back to their ancestral economic activity. Their solutions to the actual threatening of water resources vary from improving irrigation techniques and crop seeding, training programs to protect and invest on whatever is left of irrigated land for *ejidatarios*, regulation of the informal water market establishing limits to water rights concentration and price controls. On the other extreme, their options also include looking for employment opportunities in services or industry sectors, migrating to other regions and accepting the eventual disappearance of the *Ejido* as legal and productive figure.

> We think that the tendency of this irrigation district is to disappear, we don't have many options…the urban footprint is already over us (Irrigation District, 2009).

> This generation is not interested in agriculture or cattle, they are more focused on *maquiladoras* and services industries…they earn more there and more easily (Irrigation District, 2009).

> Can you see the *Ejido* here? There is no *Ejido* here anymore; all of their land has been sold to new urban developers, so they only rely on what they can get from leasing water rights (Irrigation District, 2009).

These solutions or foreseen scenarios still do not impact the degradation trend of region's water resources. They only address short-term possibilities to overcome users' social and economic needs.

Researcher Comment

To summarize, academics proposed a more effective involvement and enforcement of federal and state authorities in the solutions; authorities proposed a neutral position waiting for water users and academics agree on the solutions; cities expect solutions will come from agreements between federal and state agreements with large users, while they concentrate on improving physical and economic efficiency; industries and private users focus on the solutions of their own business productivity; and *ejidatarios* look for any means to adapt to everyday needs (income, employment, scarcity).

It is no coincidence that solutions to address the aquifers' mining condition are simply not seen. There is no real interest in actually redefining the trend, since efforts are focused on adapting to the possibilities of continuing on with small-step changes, regardless of the threats this strategy might mean in the long term. The Laguna region does not account for the conditions to address a successful water planning process if the variables of reliable data, trust and communication among parties, agreement on problem identification and therefore problem solutions, can be considered as the main characteristics a planning process must have in order to be consistent, effective and sustainable in the long term.

Limited Notions of Sustainability

All groups recognized the "notion" of sustainability, however, for practical purposes and when it comes to applying the concept to each groups' needs, priorities and water uses, these different notions of sustainability have different levels of appreciation and, therefore, different levels of sustainable consciousness among different stakeholders. For the academic sector and the generality of state and federal managers, the definition of sustainability adopted in 1988 by the Food and Agriculture

Organization of the United Nations Council (FAO) was a common definition agreed upon by those groups. This definition reads as follows: "Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development… conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO Council, 1988). Thus, hydrological and also social, economic, technical, and political considerations ought to be taken into account when leveling potential for sustainability. Given the complexity, ambiguity, abstraction and timeless indicators contained in this definition, decision-making process, communication flows, society involvement, education and definition of priorities do not portray the purpose of a sustainable approach. On the contrary, it reflects a passive attitude towards the problem. As one academic said:

> We need to be consistent with the definition. We need to protect our natural resources, but also we have to take care of economic concerns and political acceptability…All at the same time, that's why we can't move forward that easy (Academic, 2009).

For planners, sustainability seems to be a vague idea of what should be done from a broad perspective, but again, the impracticality of the definition, has turned the management approach into a "concept" or an abstraction of a notion.

> Yes we understand and we need to look towards sustainability…it's the ideal, but we have to be real meanwhile (State Official, 2009).

Likewise, given the lack of data access to communal users and their priorities focused on getting revenues from selling and renting water rights, on one hand, and the short-term issues that urban users concentrate their efforts in, on the other, their notions of

sustainability are poorly attended; their priorities are far more sensitive for social and economic implications than the sustainability of the water resources itself.

> We are very proud that we can assure water for the city for the next four or five years…Nobody has done that before (City Official, 2009).

> We are hoping to get more water this year from the reservoir that would help us solve the pressure for community leaders for at least this year…(Irrigation District, 2009).

At the same time, the responsibility to consider and actually address a sustainable water use approach is not considered to be equally necessary along sectors. For cities, their water preference over other uses has created a *de facto* alienation of a sustainable notion, given their genuine priorities to concentrate on increasing the water supply, infrastructure improvement and in the best of cases, water treatment. Notions of water demand management are far from being considered.

> We are supplying at least 50 percent of the population, but we know more percentage have access to water, but they don't have meters. There is no way I can concentrate on a sustainable approach when half of my population doesn't have meters yet and the other half doesn't want to pay (City Official, 2009).

In the case of private irrigators, the sustainability notion is overweighed on the economic and social priorities and concerns. Rural employment, economic development, and political implications of being the milk basin of the country and the most important meat producer in the north eastern region, are indeed, considered highly important for the sustainability of the region from an economic, social and political perspective.

> From my point of view, it is even more risky to stop pumping water at this point, than to keep going the way we are doing it…I know that my business and the business of everyone like me, will be seriously affected (Private Irrigator, 2009).

As it has been said, notions of sustainability in the Laguna region are also related to the different meanings and perceptions of water among different users, and of course, those perceptions also impact their levels of vulnerability to a water scarcity condition.

Vulnerability Analysis

From previous results, an accurate analysis of vulnerability in the region has to account for differences in problem identification among categories, data access, quality of their solutions (short or long term), and the relationships between their economic, social and political conditions, to the actual hydrological state of the region. For the objectives of this paper, vulnerability means the characteristics of a person or group and their situation that influences their capacity to anticipate, cope, resist and recover from the impact of a natural event, process or condition (Knuston *et al.,* 1998; Wisner *et al.,* 2004; Abraham, 2006).

Using the same problem identification and understanding of each of the categories' water issues, an attempt to portray their particular and specific vulnerability was developed. It is important to mention that each analysis does not consider the vulnerability of the hydrological basin as a whole, which is already known, but only what interviewees identified as their water-related problems in their respective boundaries of interests and priorities.

According to official predictions, the year 2025 would be a regional threshold on water availability, which is not too far away. According to interviewees, change will occur, but probably not soon enough before the depletion of the aquifer.

However, a threshold can also be instigated by economic considerations, increase in poverty and unemployment indexes, external forces (exchanges rates and international financial conditions) and even social disturbances that can define that level of vulnerability at any given time, but again, these conditions will affect not just water vulnerability or aggressive water scarcity claims, but also the institutional and structural regional system; water issues will just come with the package.

If private farmers and industries are selected, they are far from being highly vulnerable because they are already taking measures to protect their investments from

social pressure originating either from a decrease of water availability (cycle pressure) or from any regional economic vulnerable condition that may occur. For them, the claimed water scarcity scenario can be temporarily irrelevant. But if *ejidatarios* are considered, their options are shrinking; the possibilities for change into a different productive sector seem narrower, and the legal framework does not favor communal units of production but private open-market economies. For them it is real that the level of vulnerability is directly proportional to a decrease in water availability.

On the other hand, if a domestic-urban user is considered, then they have already been vulnerable to water quality issues years ago, and the tendency is to alleviate these matters in the short-term. Still only the highly sensitive political issues, such as health threats by arsenic contamination, have taken the attention of stakeholders at this time, and investment on physical and economic efficiency keeps calling itself as the priority, neglecting the fact that at the worst case scenario, they are actually not prepared to face a water crisis. There are no contingency plans that offer more coping options than extraordinary pipe water distribution. And in any case, if there are other contingency plans, they are not available to the public.

> We do have a master water plan, but is not public (City Official, 2009).

> What we do when we don't have enough water is to cut the supply for a certain given days of the week…and we take water pipes to marginal communities, that is how we deal with it (City Official, 2009).

In this case, the cities' population is highly vulnerable since the claim of a predicted water scarcity can be real at any giving moment, either for quality or quantity water issues, and they are by no means prepared technically, administratively or institutionally to resist the foreseen water threats. This scenario is portrayed ignoring the fact that if an event of water crisis occurs; the water allocation priorities would favor city users, thus reducing their level of vulnerability, in detriment of other sectors. However, this fact

does not reduce the vulnerability of the region's water resources in the long term, particularly since the possibility of moving out of the region is not a negligible option.

> The only option would be to move out from here when water runs out…If we run out of water, we just move somewhere else (City Official, Academic, Private Industry, 2009).

The problem behind the academic category as it has been noticed, is mainly the lack of communication with rest of the society, which is worsened by deficient research on water planning and management under scarcity conditions and, of course, by insufficient hydrogeological scientific work in the region. The peculiarity of this sector, given the eroded communication flows, distrust, and vicious feedback, is that it impacts every sectors' possibilities to adapt, resist, improve, cope or look forward to more sustainable scenarios and the level of impact is directly proportional to the level of vulnerability at any given time of any specific sector. This means that research and data insufficiency, ambiguity and poor communication, just make things worse for everyone. As categories tend to identify less water related problems as the main issues causing the actual water degraded condition, the risks to sustainability tend to be higher, and so the vulnerability. As an expert expressed:

> It is easier to find new sources of water, than to reach an agreement at this point (Academic, 2009).

For State and Federal authorities, considered as the framework that holds, guides and rules the other categories of stakeholders, risk and vulnerability are not only higher as key players, but to those that "depend" and "expect" actions from them. Today, planning strategies and even planning processes are practically nonexistent, or even worse, have to be that way for the *system* to keep working. For a manager, water scarcity means political, economic and social pressure at any decision-making level. They are able to recognize a water problem, but that tends to be the end of the story.

> We hope that society will change its values so it can force the institutions to change (City and State Officials, 2009).

Up until now, agreements seem to favor research to look for new sources of water, but not to plan for a sustainable future. In this case, the vulnerability risk for making decisions is higher than water scarcity itself. And, as economic productivity based on high consumptive water resources becomes more important to the region, the higher the vulnerability for planners and managers to change the actual unsustainable development model. There is no water scarcity problem, but planning scarcity issues that historically have impeded and damaged the management of the region's water resources, because other priorities have led the agenda (Salas, 2002, Wolf *et al.,* 2006; Hernandez, 2006; Hernandez A., 2006).

The Laguna region can be considered at high risk of vulnerability, not from water scarcity originally, but from planning, preparedness and willingness for change, institutional leadership, scientific research and communication among sectors that have led the region to a dangerous water scarcity future.

CONCLUSIONS

Several conclusions and important findings have to be recapitulated. First of all, there is a general knowledge in the population that something is wrong with the way water resources are managed in the region. Hydrologically speaking, the region suffers from water stress condition and the predictions of future water availability based on actual use expect a severe water stress condition for 2025. However, it also true that the actual condition does not affect equally among sectors, and certainly their priorities and solutions might not be related to the degradation of water resources, but rather to immediate short-term water related issues. The overexploitation of water resources, mainly groundwater, is left aside as somebody else's responsibility to attend to at somebody else's cost (economic, political or social).

The origin of the non-functional planning process in the region is lack of data and ongoing research. The available data, either for future research or for general knowledge, is limited, especially that related to the aquifer (Principal). Today, there is no available

information on water reserves in the aquifer. General guidelines on the evolution of the legal framework, the milk and cattle industry, economic productivity, irrigation techniques, water treatment (arsenic removal) water pricing and historical evolution of the region, guide the region's available research data. Some hydro-geological research has been developed at a basin perspective from the federal government, still, groundwater hydrogeology has been poorly addressed, and what is even worse is that it is not properly accessed or communicated to the community and stakeholders. Despite this fact, the scientific community pressures for decision-making processes, arguing there is enough evidence to look forward for a change, while decision-makers, managers and planners, still call for more and reliable data. At this stage, private users and farmers rely on their own data to overcome their particular water issues, while *ejidatarios* and small cities with limited access to any available data keep relying on what federal and state authorities decide.

The effects on the planning process that start with lack of data and research get even more deteriorated when trust and communication among sectors or categories is disturbed and eroded by political differences, economic implications, social conditions and institutional short-term priorities. Communication among water users and managers gets noisy when the squeaky wheels of everyday water problems, political rivalries at state, city and federal level, economic pressure by large water consumers of the milk and meat sectors and the different languages that prevail between decision-makers and the scientific community, result in an environment of distrust, deafness, poor feedback, disappointment, and worst, low expectations for positive change. Forecasts for the region, based on the interviews, do not offer by any means a possibility for a better condition of the water resources.

As a result of the previous condition, when trying to identify the reasons, causes or problems concerning the actual water resources, solutions and responsibilities to solve them do not correspond to what is needed for the sustainability of the region, only to solve short-term problems and partial conditions with limited effect on the actual trend. The responsibility seems to be proportional to specific, easy identifiable, everyday

issues, not to the long-term whole picture. Responsibility's lines are well delineated when it comes to jurisdictions, decision-making and priorities. "It is true what you say about responsibility, but we have no jurisdiction on groundwater, we as a state, can't touch them by law" (State Official). For cities, their main problems have to do with water utility bills not paid by a large percentage of the population, which at the same time is related to a social condition of poverty and pressure on community leaders that use water as means to obtain privileges or other demands. On the other hand, the lack of investment and resources to improve infrastructure has impeded water access to marginal communities and has affected physical and economic efficiency of water utilities. Their dependency on State and Federal funding for their physical and economic efficiency limits their perceptions of responsibility and minimizes the real water scarcity threats they might face in the near future, regardless of their present responsibility and jurisdiction over the matter.

In the case of large irrigators and *ejidatarios*, problem identification is not only interrelated, but correspondent to a given hydrological, social and economic condition. Water revenues from selling or renting water rights for low income farmers and *ejidatarios* lead their claim for water demand; and, large private water buyers take advantage of the lack of policies designated to limit or establish an agricultural frontier to concentrate water rights, although the social cyclic pressure has also encouraged improvement in irrigation techniques and water savings.

For state and federal authorities, the problem is a disagreement between water users on what priorities should be attended first and a cultural reticence to change. The problem is not the regulatory scheme, but the actors banded by those regulations that seem to reject limits to overexploitation, growth and accountability for a sustainable future. The political and economic costs for any decision that contradicts the actual model of development are too high for anyone with a temporal political appointed responsibility.

It is precisely this neutral-passive attitude that state and federal authorities have a problem with, according to the scientific community that has limited the region's

capabilities towards a more sustainable future of water resources. Lack of enforcement of the regulatory framework and soft legal instrumentation of binding mechanisms have caused abuse, excess and impunity of large water consumers and have contributed to a *de facto* condition in which informalities in the water market, illegalities on pumping rates and inequalities on water rights became the steady-state condition in the region.

Disagreement about the solutions is just a logical result. If they can't identify the same issue, there is no way they can agree on the same solutions. Academics proposed a more effective involvement and enforcement of federal and state authorities as a solution; authorities proposed a neutral position waiting for water users and academics to agree on the solutions; cities expect solutions will come from agreements between federal and state agreements with large users, while they concentrate on improving physical and economic efficiency; industries and private users focus on solutions for their own business productivity; and *ejidatarios* look for any means to adapt to everyday needs (income, employment, scarcity).

From a regional-hydrological perspective, the Laguna is considered under water stress condition and it is predicted that by 2025, the region will be considered to be under a severe water stress condition (CNA, 2004). From categories of users and stakeholders' perspectives, vulnerability does not measure equally among them. Timing, needs, priorities and preparedness vary among sectors. The vulnerability that *ejidatarios* can face under a water scarcity condition, considering water as means of income and employment, are higher than domestic and urban, because they not only need water for human consumption, but as earnings to fulfill their economic needs. It is also higher than that of private farmers or industries, because the private sector is already taking measures to cope and resist a water crisis. Likewise, cities and urban users are more vulnerable than the private sector as contingency and coping management plans for a critical water situation are not even considered. Insufficient involvement of state and federal authorities to plan for risk and crisis management, and lack of research on water planning strategies have lead the region's population to a high risk condition at any critical water scarcity condition. Furthermore, the abstraction of the notion of

sustainability among stakeholders and its intrinsic complexity over environmental, social, political and economic priorities has limited their notions of practicality and has obstructed the encouragement of proactive solutions.

To conclude, and after identifying the main issues behind the present condition of the Laguna's water resources according to the perceptions of key representatives of each sector, several general ideas could help improve and alleviate the complexity of the interrelated issues that do not only depend on the physical condition of the water resources, but the institutional and mechanistic condition of the relationships among stakeholders. Any new strategy or alternative for planning must include an integrated research program that could identify mean priorities on research for short and long term perspectives; it should consider needs, perspectives and participation of all water users; it should promote the development of a mechanism that helps identify the problems and develop a communication strategy that improves trust and effective feedback among stakeholders, specifically between the scientific community and the rest of the sectors. Likewise, this mechanism should efficiently inform society of what are the main problems, the risks and the institutional responsibility towards the population and vice versa.

V. STAKEHOLDER RATINGS OF THE PREFERENCE AND FEASIBILITY OF SELECTED WATER PLANNING STRATEGIES UNDER IMPENDING WATER SHORTAGES IN THE LAGUNA REGION, MEXICO

SYNOPSIS

The preference and feasibility analysis (PFA) developed in the Laguna region has shown that high-impact alternatives to reduce groundwater extraction in the region tend to have preference among stakeholders, but not enough levels of feasibility given the high dependency to groundwater for agriculture production to supply the largest milk basin in the country. Soft or low impact alternatives such as research, conservation campaigns and water saving projects lead the highest values of preference and feasibility. There is also an agreement to maintain the actual hierarchy on the environmental decision-making process. Given these results, no drastic changes can be expected in the water management process in the region, thus only a critical hydrological condition could be considered to open a threshold on the redesign of the water resources planning in the region and to improve its vulnerability.

INTRODUCTION

The Laguna region is a closed basin located at the southern edge of the Chihuahua desert in Mexico. It forms the western border of the state of Coahuila and eastern border of the state of Durango. Rainfall is limited (250 mm annually) and evaporation rates are extreme (2,500 mm annually) resulting high aridity. In spite of these desert climatic conditions, irrigated agriculture flourishes in the region and is a dominant sector of the economy. Surface water from mountain reservoirs and groundwater provides water for agricultural irrigation, whereas the cities and industry rely on groundwater. Approximately 1.4 million people reside in the area making it the 9th largest population center in Mexico. Just over 80% of the population lives in three cities (Torreon, Gomez Palacio and Lerdo). These cities, plus another four (Mapimi, San

Pedro, Matamoros and Francisco I. Madero), operate 70% of water wells and use 96% of municipal water use in the region (Garcia and Guzman, 2007).

The region faces a number of water related challenges including a declining aquifer, limited opportunities for new supply development, aging infrastructure and improvements in conservation. Perhaps, most critical is the over pumping of the aquifer that is the primary water source for the cities and agriculture. Data from the Comisión Nacional del Agua (CNA) and from local well logs indicate that the current groundwater pumping rates are resulting in a dramatic decline in the water level of the aquifer and in the region's water supply (CNA, 2008). Current planning projection indicates this decline is not sustainable and if continued will lead to reduced water availability and dramatic shifts in the regional economy. Irrigated agriculture, as the dominant sector of the economy, could be significantly impacted as less water will be available for this use.

Literature on analysis of planning alternatives under water scarce condition is not extensive. If planning for drought is considered as part of a water scarce condition case, then the work by Wilhite *et al.* (1987, 1993, 2001, 2004) appears the most important reference for planning, mitigation and preparedness for drought, mainly in the United States. Case study research has addressed shortages in India, China, Israel (Wiener, 1964), South Africa (also see Herbolond, 1993) and Australia (Boughton, 1991). Likewise, other research work has been completed in Africa, mainly in Ethiopia (Ottaway, 1986), Kenya (Smucker and Wisner, 2007; Iro and Long, 2007) and Canada (Wheaton *et al.,* 2008). In the case of Mexico, there is not much literature on planning for water scarcity; the research is focused mostly on analyses of drought impacts, adaptation and vulnerabilities (Liverman, 1990, 1999), and lessons learned by scarcity on the Rio Grande basin (Mumme, 1999; Chavez, 1999). There are also official water-scarce planning and cause analysis presented by the United Nations Development Program (UNDP, 2006) focused on underdeveloped countries, and by the Economic Commission for Latina America and the Caribbean (CEPAL, 1994).

WATER PLANNING AND MANAGEMENT IN MEXICO

Over-drafting of limited recharge aquifers throughout Mexico resulted in significant changes national legal reforms governing water rights, hydrologic basin planning and management. These reforms established a federal permit system for groundwater pumping and allowed for the voluntary transfer of pumping permits. As a result, some groundwater rights trades have begun between industry and agriculture (Bruns *et al*., 2004).

In addition to water rights reforms, Mexico enacted institutional reforms on water planning and management. Over the last two decades these reforms followed a concept of Integrated Water Resource Management promoted by a number of international organizations (Biswas *et al*., 2005). These reforms were strongly linked to major shifts by the national government toward pro-market policies enabling water users and stakeholders a greater role in water allocation, planning and management (Bruns *et al.,* 2004). Mexico's reforms are predicated on (1) establishing federal institutions to administer the water laws; (2) defining the role of the federal and state governments in water administration (3) integrating surface and groundwater planning and management; (4) establishing and administering a federal water rights system and authorizing water transfers; (5) decentralizing federal planning functions linked to 13 hydrologic regions; (6) involving water users, stakeholders and citizens in planning and management; (7) reducing subsidies to agriculture and (8) reducing the overpumping of aquifers.

Mexico adopted a Ley Nacional de Agua (LNA) in 1992 reaffirming a federal water rights system and establishing federal basin water management agencies. The CNA is the federal agency responsible for water policy, water rights, planning, water supply, irrigation and disaster planning. The Ministry of Environment and Natural Resources (SEMARNAT) has the responsibility for managing CNA. Basin Authorities (BA's) are regional offices of the CNA established to work at a regional level on planning and policy development. The 2004 amendments to the LNA transferred some managerial and planning responsibilities to regional basin agencies in order to decentralize some of the planning, research and management responsibility. However,

the final authority for planning and management still resides with the federal government (Scott and Banister, 2007).

The LNA established a federal permit system for granting rights to pump groundwater. Theoretically, anyone currently pumping groundwater, or anyone seeking to pump groundwater, must obtain a permit before extracting groundwater. Permit transfers are allowed in order to reallocate water to new uses or to meet changing conditions. This change is expected to create a market for water rights (National Research Council, 1995). Another important provision is the restriction on granting of new water rights on fully appropriated basins.

As a result of the reforms of the 1990's, Mexico is shifting from a supply enhancement plan prepared by consultants to a stakeholder based process. Among the factors driving this are high construction cost, limited new supplies, imperatives for greater efficiency through conservation, and increased stakeholder involvement in decision-making. The World Bank, which provided funding for some of Mexico's water planning and infrastructure projects, has adopted a stakeholder involvement planning framework emphasizing "decentralized management and delivery systems." This framework is used by the Bank to guide their funding decisions in regions where significant water scarcity problems exist (World Bank, 1993). Traditional planning and management approaches relied on experts to prepare plans. These plans place a significant reliance on supply development based on reservoirs and aquifers. The paradigm of dam building and increased aquifer pumping, while still entrenched in national water planning, is under greater scrutiny.

In the case of the Laguna region, the lack of research related to water resources planning and moreover, planning under a water-scarce condition, is one of the main deficiencies of the national and regional scientific community. There are national papers that refer to the history of water regulation on the Laguna region, (Navarrete and Melville, 2004; Hernandez, 2005), which deal with the historical relationship between groundwater regulation, economic development and national events, and give a general overview on how the policy development had to be adapted or restrained by economic

priorities or the predominant interests of the region. The literature that addresses different issues related to the overexploitation of the Acuifero Principal is mainly related to the subsequent economic activities that are sustained by groundwater extraction: the dairy and meat industry in the region and their socioeconomic impact, which is highly important for the region's development (Garcia and Guzman, 2007). It is important to mention, that that literature is mainly national, there are practically no foreign studies that address these issues. Actually, there is more analysis of the fact that there is no data, another issue being that there is no interest in dealing with planning policy issues. There are no sustainable models considered or vulnerability assessments in the region. Moreover, there are only few studies on the efficiency of irrigation systems in the region, and subsequently, there are no alternative analysis of possible scenarios of a different policy strategy that could ameliorate the water stress condition in the aquifer (CNA 1986, 2002, 2004; Rochefort and Cobb, 1994; Cruz and Levine, 1998, Hernandez, 2004; Hernandez, 2006; Guzman *et al.,* 2006; Garcia *et al.,* 2006).

RESEARCH OBJECTIVE

The purpose of this study was to identify water stakeholder preferences for an array of management options to address declining water availability. Strategy categories included development of new sources, increases in price, reduction of subsidies, reeducation of pumping, conservation, increased irrigation efficiencies, changing crops, and education. A preference –feasibility analysis was used to measure acceptance of these strategies. Results from this research could help with the design of a stakeholder framework for planning and management of the region's water resources.

STUDY AREA

The Laguna region is a closed basin located at the southern edge of the Chihuahua desert in Mexico. It forms the western border of the state of Coahuila and eastern border of the state of Durango. It is considered a closed desert basin fed by the Nazas and Aguanaval Rivers (see Figure 5.1). It is urbanized with a metropolitan population of approximately 1.4 million located in fifteen cities (10 in Durango and five in Coahuila).

Figure 5.1 Location of the Nazas- Aguanaval Basin. (CNA-SIGA, 2008).

Water Resources

The Nazas and Aguanaval watersheds provide the major surface water supplies and the eight aquifers provide groundwater for the Laguna region, with the Acuifero Principal providing 85% of all groundwater use in the region. The Nazas River starts in the mountains in Durango and flows eastward forming the border between the city of Gomez Palacio in Durango and Torreon in Coahuila. Its watershed, encompassing some 71,906 km² of land, is located in and is shared by the States of Coahuila and Durango. It has a length of 560 km (about 250 miles) and discharges into desert plain east of Torreon. Two major reservoirs: the Francisco Zarco (436 cubic million meters of storage) and Lazaro Cardenas (3,336 million cubic meters of storage) both located in Durango and capture most of the flow. The Mayran and Viesca lagoons are big natural dams that constitute dry beds at the moment, and are unable to be filled due to the dams located in the Nazas River for the Mayran lagoon and the city of Matamoros being in the Aguanaval River's flood path.

There are eight aquifers in the Laguna region, from which half are considered to be overexploited. The Acuifero Principal is the main groundwater source in the region, followed by Villa Juarez and Ceballos aquifers that are considered low quality sources. The rest 5 aquifers supply a very small amount given their low storage capacity (CNA, 2005). From the total of groundwater use in the region, 85% is supplied by the Aquifer Principal which has deserved the main focus of federal research in the northeastern part of the country. According to official numbers, pumping levels show a deficit of around 600 Mm3 per year, a reduction of the water table from 30 to 120 meters and an average annual reduction of 1.8 to 3 meters (CNA, 2002). Besides the estimations of groundwater depletion for the next 20 to 45 years, the issues concerning water quality have made those predictions even narrower. According to the federal government, water quality study of 1983 the geologic characteristics of the zone and the chemical components of the aquifer morphology demonstrated that 39% of the groundwater is not recommendable for potable uses; 26% is low quality water; and, only 35% is considered high quality water (CNA, 2002).

Water Uses and Users

Total water use in the region is 2,665 Mm3, from which 91% is used for agriculture, 5.5% for urban-domestic use, 1.4% for industrial use, and 1.3% for cattle production. From the total water used in the region, groundwater supplies 51% of agriculture, 97% of urban-domestic, and 98% of industrial use and 100% of cattle use. The remaining percentages are covered by surface water (SEMARNAT-CNA, 2004; CNA, 2007). Agriculture is the major water user. This economic activity accounts for 90% of total water used in the area, and the last twenty years the unsustainable pumping rates have leaded the region to an overexploitation of the main aquifer (Acuifero Principal). This aquifer supply 85% of the total agriculture groundwater demand, and the rest 15% supplies the total water requirements for cattle, industrial and domestic water demand (CNA, 2002, 2004, 2008).

Given the proportions of water use for different economic activities, and the regional participation of the nation's agricultural and cattle production, it would be

expected to account for a large proportion of Gross Regional Product (GRP), however, the agriculture sector represents only 6.8% of GRP from the region, while the industry and services sectors represent 93.2% (Garcia and Guzman, 2007). Agriculture and cattle production by itself does not represent wealth to the region, and it consumes 90% of the water resources. Water pricing schemes and allocation of water considering the benefits and the highest economic value of water use, have been irrelevant or not 'socially acceptable' to water planning strategies in the Laguna region.

MATERIALS AND METHODS

A survey questionnaire was used to collect information from stakeholder on their preference for strategies. Strategies were developed from the literature (Kaiser, 1998; Silvy, 2005; Texas Water Plan, 2007) and from prior personal interviews with 30 representatives of the different sectors of water users, managers, officials and experts at city, state and national level in the region (See Table 5.1). Five groups were identified: federal and state water managers, cities and urban officials, private users (industries and private irrigators), communal users (small irrigators or *ejidatarios*) and academics or experts. A total of 35 strategies were developed and respondents were asked to rank their preference and feasibility for each strategy on a 4 point Likert-scale. The survey design is presented in Appendix A and is divided in two parts: Preference (high=4, medium=3, limited=2, none=1) and Feasibility (high=4, medium=3, limited=2, none=1) of each strategy. The survey was personally delivered to each of the 49 water stakeholders and it was completed and personally returned to the researcher.

Table 5.1 Distribution of Interviews Conducted in the Laguna Region.

Categories	**Sectors**	**No. of Interviews**
Federal	Coahuila, Durango	2
State	Coahuila, Durango	2
Cities	Torreon Mapimi Gomez Palacio (2) Fco I Madero Matamoros Lerdo	7
Water users	Industry	2
	Private farmers	3
	Ejidos	3
	Urban (Torreon, Gomez Palacio)	2
Academics	Private and Public	9

Data Analysis

Preference –feasibility analysis (PFA) was used to identify and measure acceptance of the 35 different strategies by the water stakeholders. This type of analysis is a modified version of Importance-Performance Analysis first used in marketing research by Martilla and James (1977) but adapted for stakeholder decision-making in water planning (Kaiser and Binion, 1998; Kaiser *et al.,* 2000; Collins, 2000; Silvy *et al.,* 2004). The PFA technique identifies strengths and weaknesses by comparing two criteria that stakeholders use in making choices: the relative importance of their preferred option and the likelihood of success based on its relative feasibility. Feasibility can be based on legal, economic, technical, political, or public acceptance factors. By using a mean measure of central tendency, the attributes of performance and feasibility scores are ordered and classified into high or low categories. Then by pairing the two sets of rankings, each attribute is placed in one of the four quadrants of the PF grid (Figure 5.2). Strategies in the upper right corner are strongly preferred and highly feasible. The lower right quadrant will contain strategies highly feasible but not very preferable. The upper left size contain strategies strongly preferred but not very feasible. The lower left size will point the strategies that need to work on both preference and feasibility. PFA is an

especially useful tool to illustrate differences and similarities among and between groups when there are multiple choice strategies that can be adopted. It is also useful to direct resources to areas where resolving issues of feasibility can lead to adoption of strategies that are preferred.

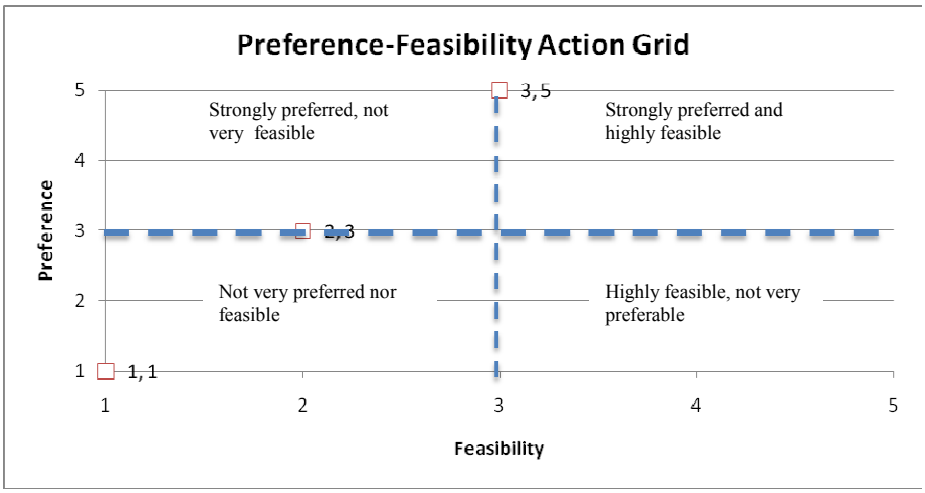


Figure 5.2 Preference and Feasibility Plot. (Adapted from Collins 2000).

Besides the PFA results, a statistical analysis using Analysis of Variance was used to examine relationships between preference and feasibility among groups, and among clusters or categories of alternatives. The results of both analyses will point to those strategies that could address more efficiently and effectively the actual state of the water resources planning process in the Laguna region.

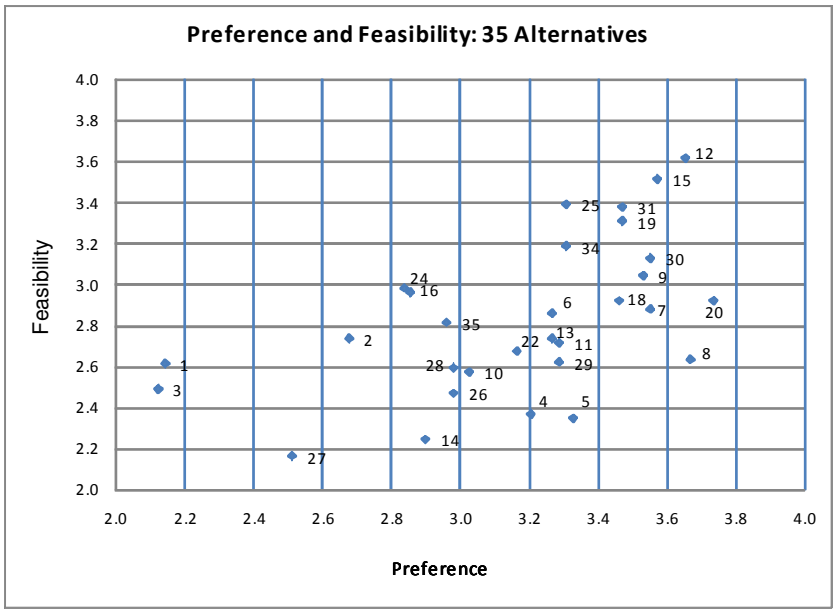
RESULTS

Preference and Feasibility: All Groups

The first assessment is to show the level of preference and feasibility of the thirty five alternatives proposed by all the interviewees regardless of their group. Considering that values below 3 do not reach the medium preference or feasibility, only the values above 3.0 are considered to be both preferred and feasible. Figure 5.3 shows the result of this first analysis. The highest values were reached by those alternatives related to more

comprehensive research over groundwater resources; water conservation through education enhancement and investment on irrigation techniques. The next best alternatives were those related to investment on water quality and physical efficiency. The most preferred, though not feasible, were the ones related primarily to water pricing, subsidies and water rights redefinition, followed by new regulations to change the actual economic development model, enforcement of actual legal regime, crop conversion, and reduction and donation of surface water use to increase groundwater recharge. The least preferred and feasible were the ones related to elimination of subsidies, forage imports to substitute the regional production, reduction to 10 micrograms per liter of arsenic the national regulation, creation of a regional water organism, decentralization of public policies to cities and states, the acquisition of water rights of the Comisión Nacional del Agua, new drillings in surrounding areas and the construction of storage tanks. Alternatives 17, 21, 23, 32 and 33 are not included in the plot because they did not gain enough ratings (larger than 2) for preference nor feasibility.

From these results, several findings are important to highlight. All groups favored investment in more integrative research that improves water savings techniques and hydrological knowledge, specifically groundwater, thus recognizing an important deficiency in the education and scientific community. These strategies do not seem to impact or affect different groups' interests or priorities and tangible results are expected to be reached in the long term. On the other side, the most preferred alternatives tend to impact sensitive interest groups, thus affecting the actual development model in the short-term. This reality limits their perceptions of feasibility favoring the softer alternatives over the high impact -though necessary- measures. They want change, but realize it is not possible, at least not at the time the survey was taken. Surprisingly, those that wanted change are not that extreme. Privatization of water rights and the decentralization of water policy are neither preferred nor feasible.



		P	F
1	Construct storage tanks that can be used during water scarcity or drought	2.14	2.61
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping	2.68	2.73
3	Drill new wells in new aquifers close to the region (for example, Jimulco).	2.12	2.49
4	Elimination of subsidies to electricity use for agriculture and cattle production	3.20	2.37
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.	3.33	2.35
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).	3.27	2.86
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).	3.55	2.88
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).	3.67	2.63
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.	3.53	3.04
10	Potable treatment of Nazas river flow for domestic-urban use.	3.03	2.57
11	Crop conversion (instead of forages, invest of new crops of less water consumption)	3.29	2.71
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.	3.65	3.61
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.	3.27	2.73
14	Establish a limit to the agriculture frontier of 50,000 hec	2.90	2.24
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.	3.57	3.51
16	Forage imports that can substitute regional production	2.85	2.96
17	Relocate the milk basin.	2.65	1.9
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.	3.46	2.92
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.	3.47	3.31
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..	3.73	2.92
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.	1.08	2.49
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.	3.16	2.67
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.	1.96	2.08
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.	2.84	2.98

Figure 5.3 Preference and Feasibility of the 35 Alternatives.

		P	F
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)	3.31	3.39
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.	2.98	2.47
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism)	2.51	2.16
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter	2.98	2.59
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).	3.29	2.62
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.	3.55	3.13
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.	3.47	3.38
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.	1.96	2.08
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).	2.12	1.77
34	Construction of arsenic removal treatment plans for urban-domestic use.	3.31	3.18
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.	2.96	2.81

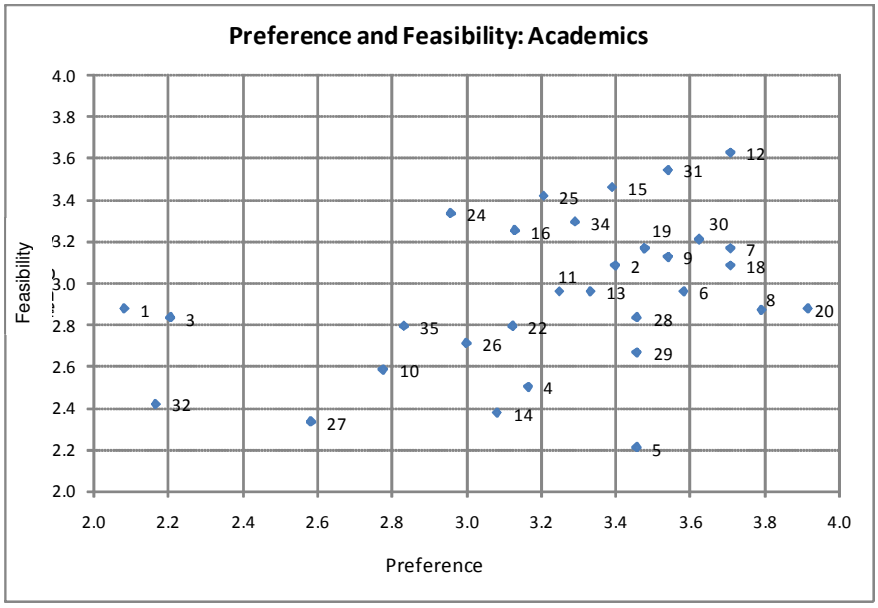
Figure 5.3 Continued.

Preference and Feasibility: Academics

Figure 5.4 presents the results of PFA for academics or experts in the region. The general tendency previously stated to favor research, conservation campaigns, education, investment in technical infrastructure and water treatment, is also shared by academics. To a lesser extent, the acquisition of water rights by the CNA (Comisión Nacional del Agua) also reaches enough levels of preference and feasibility so as to be new legal instruments to improve physical efficiency. The least values were identified on those alternatives related to look for new sources of water such as new drillings, treatment of the Nazas River for potable use and construction of storage tanks. Decentralization of public policies and the development of private cooperatives are also located in this quadrant. Again the extreme alternatives (17, 23) are not plotted for their lowest values, along with the construction of new dams and the implementation of MEVA Plan. The rest of the alternatives are located in the third quadrant which represent the most preferred, but not possible.

Results from this group are not very different from the general tendency. Again, those alternatives looking for improving research, education and conservation campaigns tend to have the higher values. The lowest values, however, concentrated on those alternatives pertained to looking for new sources of water which can be traduced in a

continuation of the *status quo* of the water resources condition that they do not approve. The alternatives related to enforcement, new regulations to limit extraction, water donation, water pricing, redefinition of water rights and subsidies, crop conversion, reduction of the national norm to 10 micrograms of arsenic per liter, remain in the preferred quadrant, but not on the feasible one.



		P	F
1	Construct storage tanks that can be used during water scarcity or drought	2.08	2.88
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping	3.40	3.08
3	Drill new wells in new aquifers close to the region (for example, Jimulco).	2.21	2.83
4	Elimination of subsidies to electricity use for agriculture and cattle production	3.17	2.50
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.	3.46	2.21
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).	3.58	2.96
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).	3.71	3.17
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).	3.79	2.87
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.	3.54	3.13
10	Potable treatment of Nazas river flow for domestic-urban use.	2.78	2.58
11	Crop conversion (instead of forages, invest of new crops of less water consumption)	3.25	2.96
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.	3.71	3.63
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.	3.33	2.96
14	Establish a limit to the agriculture frontier of 50,000 hec	3.08	2.38
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.	3.39	3.46
16	Forage imports that can substitute regional production	3.13	3.25
17	Relocate the milk basin.	2.92	1.96

Figure 5.4 Preference and Feasibility: Academics.

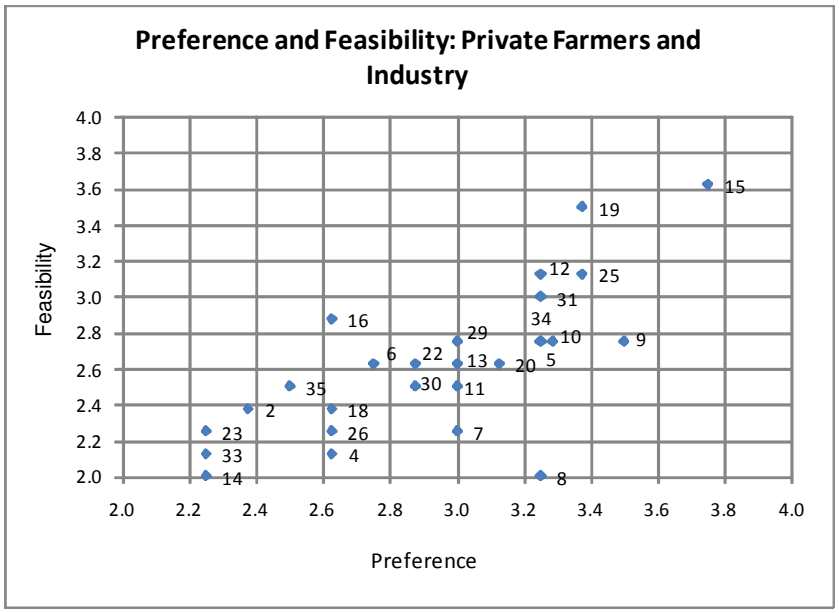
		P	F
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.	3.71	3.08
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.	3.48	3.17
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..	3.92	2.88
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.	1.00	2.71
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.	3.13	2.79
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.	1.58	2.21
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.	2.96	3.33
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)	3.21	3.42
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.	3.00	2.71
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism)	2.58	2.33
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter	3.46	2.83
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).	3.46	2.67
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.	3.63	3.21
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.	3.54	3.54
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.	2.17	2.42
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).	1.96	1.67
34	Construction of arsenic removal treatment plans for urban-domestic use.	3.29	3.29
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.	2.83	2.79

Figure 5.4 Continued.

Preference and Feasibility: Private Farmers and Industry

As is shown in Figure 5.5, for this group, and contrary to the academics grid, practically all alternatives were distributed among two and four quadrants, and the majority are located in the lowest ranges. Eight alternatives didn't reach the minimum value of 2, so they were not plotted (see shaded alternatives). These alternatives are related to new drillings, reduction of the arsenic norm from 25 to 10 micrograms per liter, decentralization of environmental policy, privatization of water resources, and the extreme alternatives (17, 21). The following alternatives located on the least preferred quadrant reflect the restrictions of the private sector to change the actual model of water use in the region. Limitation of the agricultural frontier, acquisition of water rights by CNA, differentiation and elimination of subsidies, payment for environmental services, forage imports, acquisition of wells with best water quality for urban use, reduction of surface water use to recharge the aquifer and the creation of a regional water organism,

offer clear perspectives and interests of the private sector. However, at the same time, they do not favor new drillings, construction of new dams or the MEVA Plan. They seem to recognize there is an overexploitation problem, but the offered alternatives did not satisfy their needs. This argument is explained by the alternatives this group identified as the most preferred and feasible: research on technical studies related to water reserves, cost-benefit analysis of the available alternatives, educational programs, federal investment on irrigation techniques and conservation campaigns. Once again, the call for more comprehensive research, education and investment on conservation seems to guide the decision-making planning process in the region.



		P	F
1	Construct storage tanks that can be used during water scarcity or drought	1.38	1.63
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping	2.38	2.38
3	Drill new wells in new aquifers close to the region (for example, Jimulco).	1.75	2.00
4	Elimination of subsidies to electricity use for agriculture and cattle production	2.63	2.13
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.	3.25	2.75
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).	2.75	2.63
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).	3.00	2.25
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).	3.25	2.00
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.	3.50	2.75

Figure 5.5 Preference and Feasibility: Private Farmers and Industry.

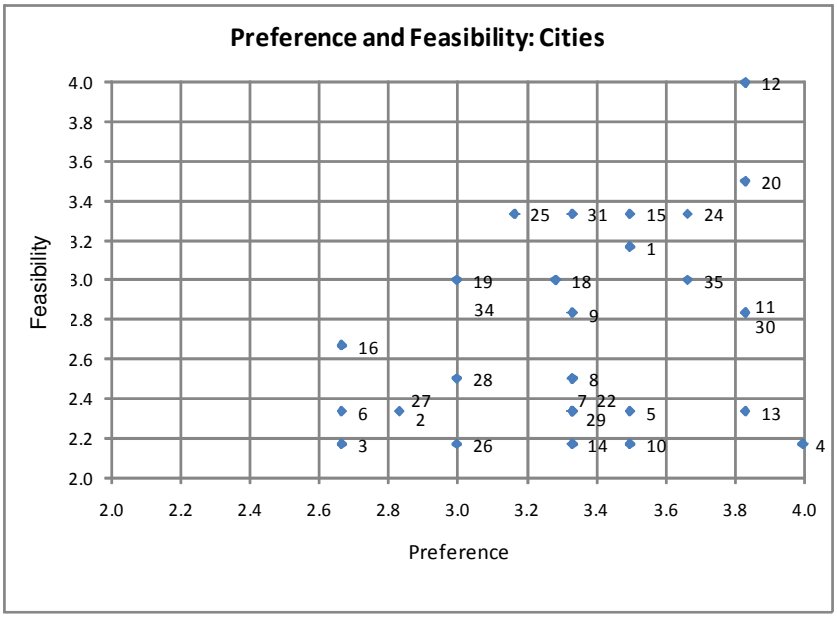
		P	F
10	Potable treatment of Nazas river flow for domestic-urban use.	3.29	2.75
11	Crop conversion (instead of forages, invest of new crops of less water consumption)	3.00	2.50
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.	3.25	3.13
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.	3.00	2.63
14	Establish a limit to the agriculture frontier of 50,000 hec	2.25	2.00
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.	3.75	3.63
16	Forage imports that can substitute regional production	2.63	2.88
17	Relocate the milk basin.	2.25	1.88
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.	2.63	2.38
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.	3.38	3.50
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..	3.13	2.63
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.	1.38	2.38
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.	2.88	2.63
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.	2.25	2.25
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.	1.50	2.00
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)	3.38	3.13
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.	2.63	2.25
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism)	2.00	1.88
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter	1.75	2.13
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).	3.00	2.75
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.	2.88	2.50
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.	3.25	3.00
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.	2.13	1.63
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).	2.25	2.13
34	Construction of arsenic removal treatment plans for urban-domestic use.	3.25	2.75
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.	2.50	2.50

Figure 5.5 Continued.

Preference and Feasibility: Cities

City officials found most of the strategies to be preferable, but only few reached high levels of feasibility (See Figure 5.6). Education, research, development of technical studies for water efficiency and conservation campaigns keep getting the highest values, but new alternatives such as the observance of the actual regulation, regulations to limit high water consumptive ornamental vegetation, acquisition of the wells of the best quality and limit them to urban use and the construction of storage tanks were also located in the highest levels of preference and feasibility. To a lesser extent, alternatives

such as payment for environmental services, new federal programs for water efficiency and the development of cooperatives such as Torreon Jardin, are located in the limits of feasibility. The lowest values were obtained on the strategies intended to acquire water rights by the CNA, new drillings in the surroundings, application of differential subsidies, forage imports and decentralization of public policies. The strategies not plotted beside the extremes 17 and 21, were the construction of new dams, the implementation of MEVA Plan and water privatization. A difference with the academic and private sector, cities tend to favor more enforcement of the actual regulation and the definition of domestic-urban priorities over other sectors. They share though the negative for new drillings, construction of new dams, the MEVA Plan, and continue on with the status quo. They also agree on the preference of more research, education and conservation campaigns and the real possibilities to attain these alternatives.



		P	F
1	Construct storage tanks that can be used during water scarcity or drought	3.50	3.17
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping	2.83	2.33
3	Drill new wells in new aquifers close to the region (for example, Jimulco).	2.67	2.17
4	Elimination of subsidies to electricity use for agriculture and cattle production	4.00	2.17
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.	3.50	2.33

Figure 5.6 Preference and Feasibility: Cities.

		P	F
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).	2.67	2.33
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).	3.33	2.33
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).	3.33	2.50
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.	3.33	2.83
10	Potable treatment of Nazas river flow for domestic-urban use.	3.50	2.17
11	Crop conversion (instead of forages, invest of new crops of less water consumption)	3.83	2.83
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.	3.83	4.00
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.	3.83	2.33
14	Establish a limit to the agriculture frontier of 50,000 hec	3.33	2.17
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.	3.50	3.33
16	Forage imports that can substitute regional production	2.67	2.67
17	Relocate the milk basin.	2.33	1.67
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.	3.29	3.00
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.	3.00	3.00
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..	3.83	3.50
21	Continue on with the status quo scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.	1.17	2.33
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.	3.33	2.33
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.	2.00	1.50
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.	3.67	3.33
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)	3.17	3.33
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.	3.00	2.17
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism), access and managmente of the region'wh states governments to plan	2.83	2.33
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter	3.00	2.50
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).d require constitutional changes-enforcmente of federalims)use and managmente of ground and surface waters,from an envir	3.33	2.33
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.	3.83	2.83
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.	3.33	3.33
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.	1.60	2.00
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).	1.50	1.17
34	Construction of arsenic removal treatment plans for urban-domestic use.	3.00	3.00
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.	3.67	3.00

Figure 5.6 Continued.

Preference and Feasibility: Communal Users (*Ejidos*)

For this group just as the previously analyzed group, research, education and conservation programs still lead the list of priorities. It also considers highly preferent and feasible arsenic removal treatment, the rescue of the best water wells for domestic consumption, the enforcement of regulations and instruments to improve water efficiency use in the cities and in agriculture (See Figure 5.7). At the same time, this is

the first group that favors the treatment of the Nazas River for potable use. The alternatives with the lowest values were the ones related to forage imports, construction of storage tanks and dams, donation of water rights, the development of new policies that could encourage a change in the actual model (from agriculture to services or industry) and the relocation of the milk basin. It is interesting that even the relocation of the milk basin is located in the lowest quadrant; it has the highest values compared to the rest of the groups. The alternatives that are not plotted given their values lesser than 2, are integrated by the negative of new drillings, elimination of subsidies to electricity, crop conversion, limitation to the agricultural frontier, privatization of water resources and continuation with the *status quo.* The rest of the alternatives are considered preferred, but not feasible enough.

This group shows the most aggressive values against any changes on the actual policies governing water use for agriculture, even more than the private sector. However, at the same time recognizes that change is needed, new drillings are not an option anymore just as the construction of new dams are not. Water treatment highlights the list of their preferences just as more integrated research, education encouragement and conservation campaigns.

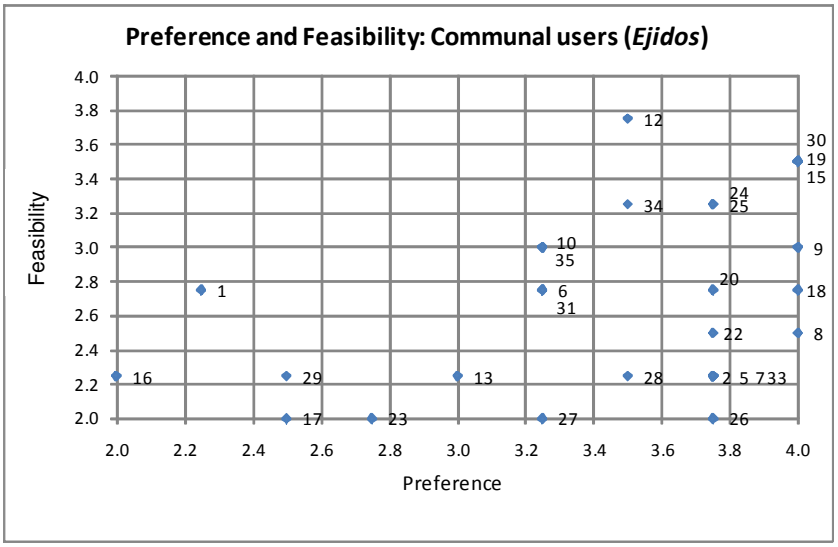


Figure 5.7 Preference and Feasibility: Communal Users (*Ejidos*).

		P	F
1	Construct storage tanks that can be used during water scarcity or drought	2.25	2.75
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping	3.75	2.25
3	Drill new wells in new aquifers close to the region (for example, Jimulco).	1.75	2.25
4	Elimination of subsidies to electricity use for agriculture and cattle production	3.25	1.75
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.	3.75	2.25
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).	3.25	2.75
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).	3.75	2.25
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).	4.00	2.50
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.	4.00	3.00
10	Potable treatment of Nazas river flow for domestic-urban use.	3.25	3.00
11	Crop conversion (instead of forages, invest of new crops of less water consumption)	3.00	1.50
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.	3.50	3.75
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.	3.00	2.25
14	Establish a limit to the agriculture frontier of 50,000 hec	3.00	1.75
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.	4.00	3.50
16	Forage imports that can substitute regional production	2.00	2.25
17	Relocate the milk basin.	2.50	2.00
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.	4.00	2.75
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.	4.00	3.50
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..	3.75	2.75
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.	1.00	2.00
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.	3.75	2.50
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.	2.75	2.00
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.	3.75	3.25
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)	3.75	3.25
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.	3.75	2.00
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism)	3.25	2.00
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter	3.50	2.25
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).	2.50	2.25
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.	4.00	3.50
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.	3.25	2.75
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.	1.50	1.50
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).	3.75	2.25
34	Construction of arsenic removal treatment plans for urban-domestic use.	3.50	3.25
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.	3.25	3.00

Figure 5.7 Continued.

Preference and Feasibility: Federal and State Managers

Research, conservation and education are their main preferred and feasible options. Arsenic water treatment and the rescue of the highest quality water wells for

domestic use also show high levels. Furthermore, they consider that a new differential subsidies policy is both needed and possible to apply. The least values were obtained by those alternatives related to the acquisition of water rights by CNA, new drillings, new dams, donation of water rights by large consumers, limitation of the agricultural frontier, forage import, creation of a new regional water organism, and the reduction of the arsenic norm (See Figure 5.8). In the line between feasible and unfeasible alternatives, the payment for environmental services, redefinition of water rights, and enforcement of the actual regulatory scheme are also located. These alternatives are preferred, but there is not enough agreement or confidence in how these possibilities could be successful, indeed reflecting the actual deteriorated perceptions of the planning process in the region.

The alternatives not considered in the plot for their lowest values are the extreme (17, 21) decentralization of public policies, privatization of water rights and the implementation of the MEVA Plan. Likewise, this group does not consider possible an important change to the actual water use model in the region, or at least, the alternatives offered didn't offer enough possibilities for them to change.

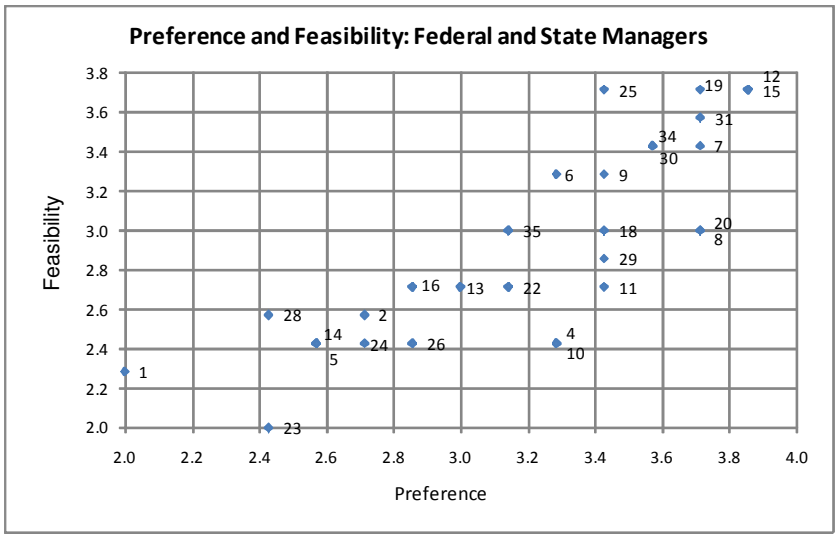


Figure 5.8 Preference and Feasibility: Federal and State Managers.

		P	F
1	Construct storage tanks that can be used during water scarcity or drought	2.00	2.29
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping	2.71	2.57
3	Drill new wells in new aquifers close to the region (for example, Jimulco).	1.86	2.00
4	Elimination of subsidies to electricity use for agriculture and cattle production	3.29	2.43
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.	2.57	2.43
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).	3.29	3.29
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).	3.71	3.43
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).	3.71	3.00
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.	3.43	3.29
10	Potable treatment of Nazas river flow for domestic-urban use.	3.29	2.43
11	Crop conversion (instead of forages, invest of new crops of less water consumption)	3.43	2.71
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.	3.86	3.71
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.	3.00	2.71
14	Establish a limit to the agriculture frontier of 50,000 hec	2.57	2.43
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.	3.86	3.71
16	Forage imports that can substitute regional production	2.86	2.71
17	Relocate the milk basin.	2.57	1.86
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.	3.43	3.00
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.	3.71	3.71
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..	3.71	3.00
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.	1.00	2.29
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.	3.14	2.71
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.	2.43	2.00
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.	2.71	2.43
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)	3.43	3.71
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.	2.86	2.43
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism)	2.14	1.86
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter	2.43	2.57
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).	3.43	2.86
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.	3.57	3.43
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.	3.71	3.57
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.	1.71	1.86
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).	2.14	1.86
34	Construction of arsenic removal treatment plans for urban-domestic use.	3.57	3.43
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.	3.14	3.00

Figure 5.8 Continued.

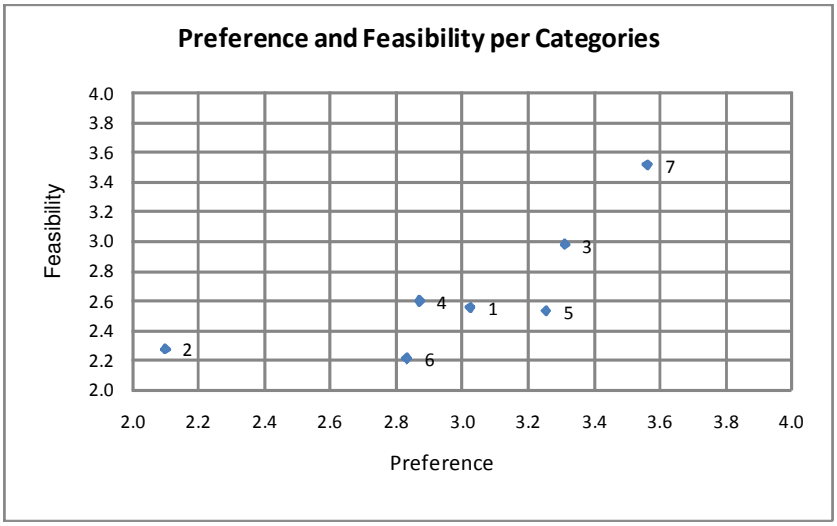
To summarize, neither group consider viable or desirable a change in the actual development model in the region related to high impact alternatives oriented to reduce

the overexploitation of the aquifer. Although, considering that the five groups voted the highest values towards more research on the actual condition of the aquifer, new techniques on water savings, and cost-benefit analysis of the available alternatives, the negative reaction to a more drastic change could be very well related to lack of reliable information that can validate the impacts on water savings, improvement on the condition of the aquifer and the region's economic, social and political vulnerability. They agree on the fact that new drillings are not an option, but called for more information and integration of the society as a whole in the decision making process.

Preference and Feasibility Analysis: Categories of Alternatives

The 35 strategies were clustered into six different categories of alternatives based on their similarities (Appendix B). Category 1 integrates those alternatives related to water and environmental pricing, subsidies elimination or redefinition and privatization of water rights. Category 2 involves those alternatives related specifically to looking for new sources of water, therefore maintaining the actual condition. Category 3 integrates those alternatives related to the development of new regulations to improve several aspects such as water efficiency and conservation for cities and agricultural use, the reduction of the arsenic norm to 10 micrograms per liter, and the enforcement of permit restrictions. Category 4 includes those strategies related to change the agricultural model of water use: crop conversion, forage imports and limits to irrigation land. It also includes the construction of new dams, the acquisition of the best water wells for domestic use, and the construction of water treatment plants and storage tanks for critical times. This category holds those alternatives that emphasize limits to agricultural use, and encourages the priority of water allocation to urban use. Category 5 is primarily related to those alternatives that pertain to reducing the amount of groundwater pumping rate either by acquisition of water rights by the CNA, donation by large consumer or during water rights transactions and redefinition or reduction of surface water use. This category is considered to have high impact effects in the actual water pumping model. Category 6 integrates a combination of two kinds of alternatives: those related to encouraging a change on the economic model (including the relocation of the milk

basin), and the decentralization of water and environmental policy. This category represents a high impact change in the management and decision-making process. Finally, Category 7 is related to those alternatives encouraging a more comprehensive research and education. This last category does not represent an immediate high impact effect on any of the groups' interests and priorities. Figure 5.9 presents the results of the seven categories.



	P	F
Category 1	3.03	2.55
Category 2	2.10	2.27
Category 3	3.32	2.98
Category 5	2.87	2.60
Category 5	3.26	2.53
Category 6	2.84	2.21
Category 7	3.57	3.51

Figure 5.9 Preference and Feasibility per Categories.

The highest values were identified in Category 7 followed by Category 3 which contains mostly low impact measures that promote more efficient water use for cities and irrigators. In the case of Category 3, the low values previously analyzed in the alternative concerning the observance of the regulatory scheme and the reduction of the arsenic national norm, affected the total mean values. It is important to notice that only

Category 7 reached the necessary values to be feasible enough; however, most of them are located in the high preferred quadrant. Previous results were reaffirmed with the lowest values obtained by Category 2 given the low preference and feasibility of the alternatives promoting the search for new sources of water, thus, assuming a necessary change away from the *status quo*; the same behavior is represented by Category 4, reflecting the negative to promote radical changes in the way agriculture has been planned and managed in the region, and Category 6, which promotes a drastic change in the production model in the region and in the regional delineation and enforcement of water-environmental laws. Categories 1 and 5 show important levels of preference by all groups, which represent two important facts: stakeholders want a change in water management using new pricing schemes and they also want a change in the way water is being overexploited. The actual conditions however, don't offer positive estimations on the possibilities that this might occur.

Statistical Analysis

Analysis of Variance and the corresponding Least Square Distance (LSD) tests were used to compare the mean preference and feasibility values between groups (Figure 5.10, Table 5.2 and Table 5.3). These figures indicate the relationships in preference, feasibility of the thirty five alternatives for each group, and the corresponding differences between preference and feasibility for each group. The private sector differed significantly (95% confidence level) in their preferences compared to the other four groups. For feasibility there was greater variability among the groups. The Academic sector had differences with private, city, and communal sectors and the private sector had differences with the federal-state group.

There is little disagreement on preferences among stakeholders, except for the private sector. But there is more disagreement when it comes to feasibility, especially for the private sector followed by the communal and city sectors. Interestingly, academics and federal-state sectors do not seem to contradict each other in their measurements for preference and feasibility. Variables such as information access, experience and similar

broad knowledge about the actual conditions might be factors concealing these similar perspectives.

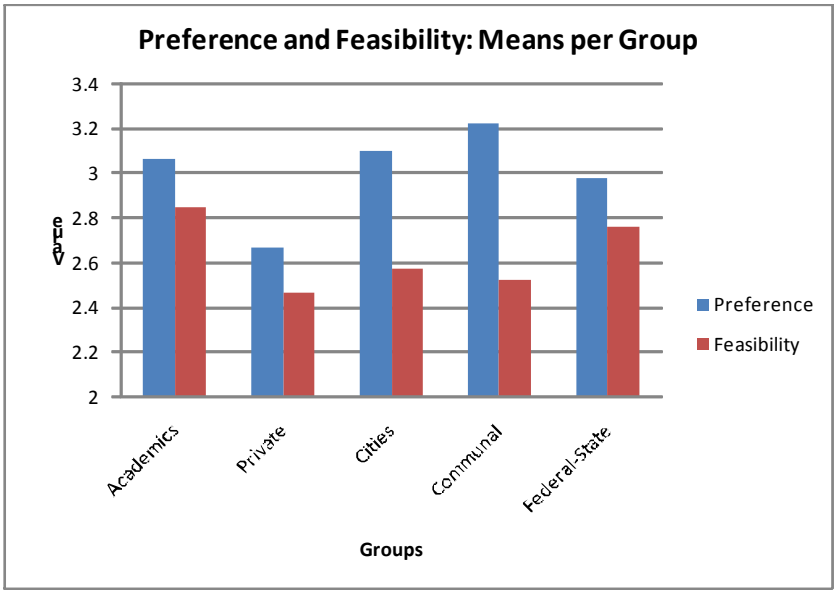


Figure 5.10 Differences between Preference and Feasibility: Means per Group.

Table 5.2 Differences in Preference and Differences in Feasibility per Group.

Differences in Preference per Group		**Sig.**
Private	Academics	0.017
	Cities	0.010
	Communal	0.000
	Federal-State	0.065
Differences in Feasibility per Group		**Sig.**
Academic	Private	0.003
	Cities	0.038
	Communal	0.014
Private	Federal-State	0.024

Table 5.3 Differences between Preference and Feasibility per Group.

Group	Sig.
Academics	0.116
Private	0.132
Cities	0.001
Communal	0.001
Federal-State	0.169

Recommended Future Directions

Based on the above results and the literature reviewed on planning for water scarcity, important highlights and new ideas for the Laguna region can be considered for future water planning in the area. The first highlight is necessary related to research and more data, but not only research *per se,* but with a shared purpose and with specific objectives. The objectives can be related to immediate, medium or long term solutions, but have to be necessarily related to fulfill a social need agreed and consented among the stakeholders. The process of doing research and given the eroded communication of the participating institutions could consider external actors (i.e., outside academic institutions, either national or foreign) that can play a mediator, neutral and objective position when it comes to data acquisition, process, evaluation, monitoring, revising and communication of the results to water stakeholders. However, if this alternative is considered, consent among the Laguna region must necessary go along with recognition and definition of the external actor responsibilities before it is considered to pursue applied research development in the region. Experiences around the world in arid areas that depend heavily on their water resources for economic development have considered and included at different levels the participation and monitoring of external actors as mediators in the data collection process or research objectives development. Transboundary examples are the Jordan river basin, in which the riparian states relied successfully on neutral expertise of international organizations such as the United Nations and representatives of the European Union, to develop integrative research, define priorities, overcome discrepancies and improve communication among

stakeholders (Haddadin, 2006). Another similar case is the Mekong river basin, in which participation of all stakeholders guided by international organization participated in the decision-making process of the water planning of the region's water resources (Pech and Sunada, 2008).

The concept of River Basin Development Planning and Management (RBDPM), that involves the main activities of planning, management and conflict resolution using a permanent communication mechanism, attempts to include not only the water resources planning process towards sustainability, but also pursues a development tool for improving social and economic conditions of stakeholders (Barrow, 1998). This concept integrates the idea of the planning process as a multipurpose, comprehensive, integrated and holistic approach to address priorities, needs, economic and social conditions and different perspectives of water stakeholders that could be very well suited for the present case in its way towards defining research priorities, objectives (environmental, social and economic) and mechanisms of communication. The case of New Mexico also represents a theory case in which the planning process towards a urban water conservation campaign given the drier climate changes predictions in the region (such as the Laguna region) included as the first and main priority the reliability and development of data and education programs that could enhance research and overcome social, technological and economical barriers to change (Funk, 2007). Likewise, important experiences in the development and use of data and new technologies as a result of an integrative decision-making process can be found in the case of the Colorado River Basin (Garrick *et al*., 2008), in the Heihe river basin in arid western China (Zhu *et al*., 2003), and in some cases in Latin America and the Caribbean region (Dourojeanni, 1994).

The second recommended direction has to do with those alternatives related to decentralization or regionalization of the water resources planning and decision-making process. As it was stated before, results of the preference and feasibility analysis did not favor those alternatives related to either decentralization of the planning process or decentralization of the decision making process at a regional, state or city level.

However, this tendency could also be explained as a consequence of lack of trust, communication and localized data on planning development in the region. The uncertainty of the actual condition of the water resources, plus the social and economic implications and distrust among stakeholders, has negatively affected the planning process and limited it to a passive steady-state condition in which nobody seems to take responsibility. This reality diminishes the preferences towards a decentralized water planning and management process. However, worldwide experiences and theory development over regionalization offer good examples and experiences in which these alternatives could be very suited for cases such as the Laguna region. The concepts of territorial organization for the management of natural resources; organization and training of the population; research on ecosystems; the strengthening of public institutions (specially the municipalities); and, awareness of the economic value of natural resources, have gained important acceptance on the development of sustainable river basins in Latin America (Dourojeanni, 1994), western China (Murphy, 2002; Zhu *et al*., 2004), and Canada (Wheaton *et al*., 2008).

Even though the federal government has created regulations that promote the enforcement of decentralization at a conservative level, water federalism has not yet been completely accepted as a proper social and economic measure to improve the management of the water resources in the country. Even though literature recalls that antagonism among federal, state and local water resource planners may be due to their lack of involvement and understanding of the policy-making process given that the federal government is not capable of leadership in the all main water policy areas: distributive social, economic and physical benefits, that also have redistributive, regulatory and social effects (Hrezo and Hrezo, 1985; Hrezo *et al*., 1986).

The idea of decentralization ought to improve two specific areas in the water management process: first, improve the efficiency of water allocation, and second, build institutional capacity to cope with critical events of water scarcity, which can greatly reduce the level of vulnerability (Easter and Hearne, 1994; Wilhite *et al*., 2005) This improvement could alleviate and distress the relationship among stakeholders in the

Laguna region, and at the same time, concentrate state and city efforts on developing and enforcing their legal framework, enhance institutional response and involvement in the planning process and promote oriented conservation and water use efficiency programs designed to attend specific priorities of different stakeholders.

Finally, acknowledging the actual social, economic, hydrological and political conditions in the Laguna region, the planning process towards a possible sustainable scenario in the near future must start at soft-low impact strategies or small step changes in order to avoid disturbance in communication and acceptability of reliable alternatives. From this perspective, there is a need to start constructing from scratch institutional leadership, trust, data reliability, positive feedback and communication and look for long term sustainable results. In the Laguna region there is a genuine need to rebuild the models of science development and applied research and construct the necessary links and bridges between the scientific community, state institutions and the society as a whole.

CONCLUSIONS

From the first assessment, several findings are important to highlight. All groups favored investment in more integrative research that improves water savings techniques and hydrological knowledge, specifically groundwater, thus recognizing an important deficiency in the education and interdisciplinary research. These strategies do not seem to impact or affect different groups' interests or priorities in the short term, and tangible results are expected to be reached in the long term.

The private sector seems to recognize that there is an overexploitation problem, but the offered alternatives do not satisfy their needs. This argument is explained by the alternatives this group identified as the most preferred and feasible: research on technical studies related to water reserves, cost-benefit analysis of the available alternatives, educational programs, federal investment on irrigation techniques and conservation campaigns.

As a difference with the academics and the private sector, cities tend to favor more enforcement of the actual regulation and the definition of domestic-urban priorities

over other sectors. They share though negative reaction for new drillings, construction of new dams, the MEVA Plan, and to continue on with the status quo. The communal sector shows the most aggressive values against any changes on the actual policies governing water use for agriculture, even more than the private sector. However, at the same time recognizes that changed is needed, new drillings are not an option anymore just as the construction of new dams. Water treatment highlights the list of their preferences just as more integrated research, education encouragement and conservation campaigns. Likewise, the federal-state sector does not consider possible an important change to the actual water use model in the region, or at least, the alternatives presented didn't offer enough possibilities for them to change.

Unfortunately, the most preferred alternatives tend to impact sensitive interest groups, affecting the actual development model in the short-term perspective. New pricing schemes, subsidies redefinition, measures to stop the overpumping are moderately accepted by all groups, except by the private and federal-state sectors. Economical and political implications related to high sensitive changes on the agriculture production model based on unrestricted water pumping, have paralyzed decision-makers for moving towards a more sustainable approach of groundwater use, specially because the high revenues obtained by a low water cost supported by subsidies, makes it economically inefficient and politically unfeasible (Navarrete and Melville, 2004; Hernandez, 2006). This reality limits their perceptions of feasibility favoring the softer alternatives over the high impact -though necessary- measures. They want change, but realize is not possible, at least not at the time the survey was applied. Surprisingly, that wanted change is not that extreme. Privatization of water rights and the decentralization of water policy are neither preferred nor feasible. The redefinition of institutional jurisdiction will mean reassignment of responsibilities on planning and decision-making process through a decentralization or regionalization of water management which apparently is not preferred. This fact can be either related to states and cities institutional, legal and physical lack of preparedness issues, or the lack of

acknowledgment of a legitimate need in the actual model of water management in the region that is estimated to collapse in the next 20 to 40 years at the actual pumping rate.

The results of the second part of the analysis, once the alternatives are clustered, offer a more clear view of the tendencies of the total five groups, and the differences among them related to specific subjects and to specific impacts on different groups. All groups favor research, conservation campaigns and investment on physical efficiency for cities and irrigators. Likewise, they all agree on stopping new drillings in the area and have negative reaction to search for new sources of water. Disagreements primarily with the private sector and to a lesser extent with *Ejidos*, arise when water pricing, privatization options, subsidies redefinition and enforcement of the actual legal regime are considered. Differences also with the private and federal and state managers are important when considering decentralization of planning decision making process. At the same time, there is a general tendency that does not favor an important change of agricultural water use in the region, though they do preferred the implementation of important measures to reduce the mining of the aquifer.

All groups recognize a problem; they are willing to do something, but nothing of high impact that could change the perpetuation of the actual economic conditions, regardless of their preference to improve the hydrological conditions.

To summarize, neither group consider viable or desirable a change in the actual development model in the region related to high impact alternatives oriented to reduce the overexploitation of the aquifer. Although, considering that the five groups voted the highest values towards more research on the actual condition of the aquifer, new techniques on water savings, and cost-benefit analysis of the available alternatives, the negative for a more drastic change could be very well related to lack of reliable information that can validate the impacts on water savings, improvement on the condition of the aquifer and the region's economic, social and political vulnerability. They agree on the fact that new drillings are not an option, but called for more information and integration of the society as a whole in the decision making process. There is a genuine social need for information and affordable alternatives that could

alleviate the hydrological problem and that could address as well, social, economic and political impacts for all groups involved in the short and long term perspectives.

VI. CONCLUSIONS

The Laguna region faces the daunting challenge of dealing with a declining groundwater supply with an agricultural and municipal economy and population highly dependent on that supply. Water reports prepared by the federal government indentify the problem as over-pumping the aquifer to the extent that extraction exceeds recharge resulting in dropping water well levels, a decline in overall supply and a diminution in water quality. In response to this problem in the Laguna and many other regions in Mexico, the federal government enacted a number of reforms in planning, management and water rights. These reforms included; regionalizing water planning based on hydrologic units, seeking greater stakeholder involvement in planning, establishing federal, state and local institutions for planning and management, and establishing a transferable system of permits for groundwater pumping.

This dissertation examined the progress of these reforms through interviews and surveys of federal, state, local officials and private water rights holders. In addition, an economic impact model was developed based on different water availability scenarios.

The economic production model based on different scenarios of water availability and estimations of possible dryer conditions demonstrated the vulnerability of the system given three important facts: the unsustainable pumping rate for agriculture use, the uncertainty of water volume in the Acuifero Principal, and the predictions of more severe and constant droughts in the region in the coming years. The simulations indicate that regardless of the relativity of the economic impact to different sectors, there is enough evidence to prove that the greater the possibility of a drought, the greater the impact on economic production. Likewise, the amount of water increase in the aquifer after a hurricane event given the actual conditions of water extraction rates does not represent significantly more water for the aquifers' recharge nor for future water availability. The uncertainty of hurricane events and their short-term impact on the aquifer's water availability, overrides the idea of relying on hurricanes for future groundwater supply. Nevertheless, the amount of water in the aquifer is the origin

variable that determines both the economic production and the vulnerability of the system to dryer conditions. At the present extraction rate and regardless of hurricane events, the less water in the aquifer, the higher the vulnerability to droughts and to economic production losses.

These conclusions lead to important highlights over planning policies for semiarid regions that depend heavily on groundwater resources as their main source of economic development. The vulnerability of these systems is more related to actual pumping rates than to levels of water availability. The option towards a reduction of vulnerability and uncertainty of the Laguna region is a limitation of actual pumping rates and, at the same time, urgent investment in research of actual water volume of the Acuifero Principal and climate change at local scale.

Data from the interviews and surveys provided insight on problem identification and differing opinions on strategies and options for dealing with the problem. First of all, there is a general knowledge in the population that something is wrong with the way water resources are managed in the region. Hydrologically, the region suffers from water stress condition and the predictions of future water availability based on actual use expect a severe water stress condition for 2025. However, the actual condition does not affect equally among sectors and certainly their priorities and solutions might not be even related to the degradation of water resources, but to immediate short-term water related issues or other priorities. The overexploitation of water resources, mainly groundwater, is left aside as somebody else's responsibility and somebody else's cost.

The available data either for future research or for general knowledge is limited, especially that related to the Acuifero Principal. The scientific community pressures for decision-making process arguing there is enough evidence to look forward for a change, while decision-makers, managers and planners, still call for more and reliable data. Private users and farmers rely on their own data to overcome their particular water issues, while *ejidatarios* and small cities with limited access to any available data, keep relying on what federal and state authorities decide.

The effects on the planning process that start with lack of data and research get even more deteriorated when trust and communication among sectors is disturbed and eroded by political differences, economic implications, social conditions and institutional short-term priorities. Communication among water users and managers gets noisy when political rivalries at state, city and federal level, economic pressure by large water consumers of the milk and meat sectors and the different languages that prevail between decision-makers and the scientific community, result in an environment of distrust, deafness, poor feedback, disappointment, and low expectations of positive change. Forecasts for the region, based on the interviews, do not offer by any means a possibility for a better condition of the water resources.

As a result, when trying to identify the reasons, causes or problems concerning the actual water resources, solutions and responsibilities to solve them do not correspond to what is needed for the sustainability of the region, only to solve short-term problems and partial conditions with limited effect on the actual trend, leading the region to a highly vulnerable unsustainable condition as it was also demonstrated in the results of Section V. For cities, the main problems have to do with water utilities bills not being paid by a large percentage of the population, the lack of investment and resources to improve infrastructure and their dependence on State and Federal funding for their physical and economic efficiency. This reality limits their perceptions of their responsibility and minimizes the real water scarcity threats they might face in the near future, regardless of their present responsibility and jurisdiction over the matter.

In the case of large irrigators and *ejidatarios*, problem identification is contrasting. Water revenues from selling or renting water rights for low income farmers and *ejidatarios* lead the claim for more water, while large private water buyers take advantage of the lack of policies designated to limit or establish an agricultural frontier. For state and federal authorities, the problem is a disagreement between water users on what priorities should be attended first and a cultural reticence to change. The problem is not the regulatory scheme, but the actors banded by those regulations that seem to reject limits to overexploitation, growth and accountability for a sustainable future.

The scientific community criticizes the neutral-passive attitude that state and federal authorities have taken towards the problem that has limited the region's capabilities for a more sustainable future of water resources. Lack of enforcement of the regulatory framework and soft legal instrumentation of binding mechanisms have caused abuse, excess and impunity of large water consumers and have contributed to a *de facto* condition in which informalities in the water market, illegalities on pumping rates and inequalities on water rights became the steady-state condition in the region.

Disagreement on the solutions is also a key finding. Academics proposed a more effective involvement and enforcement of federal and state authorities in the solutions; authorities proposed a neutral position waiting for water users and academics agree on the solutions; cities expect solutions will come from agreements between federal and state agreements with large users; industries and private users focus on the solutions of their own business productivity; and *ejidatarios* look for any means to adapt for everyday needs.

From categories of users and stakeholders' perspectives, vulnerability does not measure equally among them. Timing, needs, priorities and preparedness vary among sectors. Considering water as means of income and employment for *ejidatarios*, their vulnerability is higher than that of domestic and urban users. It is also higher than that of private farmers or industries, because the private sector is already taking measures to cope and resist a water crisis. Likewise, cities and urban users are more vulnerable than the private sector as contingency and coping management plans for a critical water situation are not even considered. Insufficient involvement of state and federal authorities to plan for risk and crisis management, and lack of research on water planning strategies have led the region's population to a high risk condition at any critical water scarcity condition.

Preference and feasibility analysis revealed that all groups favored the investment of more integrative research that improves water savings techniques, education and conservation programs, cost-benefit analysis and hydrological research, specifically on groundwater reserves, thus recognizing an important deficiency in

education and interdisciplinary research. The private sector seems to recognize there is an overexploitation problem, but the offered alternatives did not satisfy their needs. Differing from the academic and private sector, cities tend to favor more enforcement of the actual regulation and the definition of domestic-urban priorities over other sectors. They share though, the negative for new drillings, construction of new dams, the MEVA Plan, and the status quo. The communal sector shows the most aggressive values against any changes on the actual policies governing water use for agriculture. However, at the same time recognizes that change is needed, new drillings are not an option anymore just as the construction of new dams is not. Water treatment highlights the list of their preferences just as more integrated research, education encouragement and conservation campaigns. Likewise, the federal-state sector does not consider possible an important change to the actual water use model in the region, or at least, the alternatives offered didn't offer enough possibilities for them to change.

Unfortunately, the most preferred alternatives tend to impact sensitive interest groups, affecting the actual development model in the short-term perspective. New pricing schemes, subsidies redefinition, measures to stop overpumping are moderately accepted by all groups, except by the private and federal-state sectors. Economic and political implications related to high sensitive changes on the agriculture production model based on unrestricted water pumping, have paralyzed decision-makers from moving towards a more sustainable approach of groundwater use. This reality limits their perceptions of feasibility favoring the softer alternatives over the high impact -though necessary- measures. Decentralization or regionalization of water management are also not preferred by any of the groups since the redefinition of institutional jurisdiction will mean reassignment of responsibilities for planning and decision-making process which apparently is not considered as an option. This fact can be either related to states' and cities' institutional, legal and physical lack of preparedness issues, or the lack of acknowledgment of a legitimate need in the actual model of water management in the region that is estimated to collapse in the next 20 to 40 years at the actual pumping rate.

Neither group consider viable or desirable a change on the actual development model in the region related to high impact alternatives oriented to reduce the overexploitation of the aquifer. Although, considering that the five groups voted the highest values towards more research, the negative for a more drastic change could be very well related to lack of reliable information that can validate the impacts on water savings, improvement on the condition of the aquifer and the region's economic, social and political vulnerability. They agree that new drillings are not an option, but called for more information and integration of the society as a whole in the decision making process. There is a genuine social need for information and affordable alternatives that could alleviate the hydrological problem and that could address as well social, economic, and political impacts for all groups involved in the short and long term perspectives.

Given these results, the Laguna region can be considered at high risk of vulnerability, since lack of planning, preparedness, willingness for change, institutional leadership, scientific research, and communication among sectors are the main characteristics that define the system and create obstacles the perception and implementation of planning alternatives towards sustainability.

LIMITATIONS AND FUTURE WORK

Limitations and boundaries of this research are also important to highlight. The results of the economic vulnerability assessment model addressed in Section III are limited by the model's own assumptions. Economic production is based on constant market prices and pumping rates. Production costs, market allocation, and revenues distribution are not considered, nor is water quality. These limitations can in fact change predictions of economic losses and could have worsened the impacts of droughts in the system. Furthermore, the data and interactions used to construct the aquifers' recharge mechanics is limited to available data and variables considered. Recharge given a drought or hurricane conditions does not account for all the geomorphologic and hydrological variables included on a typical hydrological model.

The methodological approach used in Section IV is based on information obtained, reasoned, interpreted by the researcher using a specific sample design.

Proposition analysis and theory development were then constructed under these assumptions. However, the bias of the information given by interviewees over a specific issue and the following interpretation of the researcher could have led to overestimation or misinterpretation of arguments and opinions, especially politically sensitive interviewees. Likewise, the analysis of the alternatives recommended by interviewees plus those added from literature reviewed that were analyzed in Section V, might not be sufficient or adequate to evaluate planning policies in the region. The conclusions reflect only the results of the considered alternatives, but do not intend to cover all possible options that might be available to the region.

To complement this research, future investigation will need to address several aspects suggested throughout. First, vulnerability assessments related to climate change in the region given the predictions of more permanent droughts are necessary to enhance not only acknowledgment of the unsustainable water pumping condition, but to encourage water planning strategies towards crisis and risk management approaches. Second, given the direct relationship of groundwater availability to economic development in the region, it is urgent to invest in research to estimate groundwater reserves in the Laguna region, especially those related to the Acuifero Principal. Research on this matter can alleviate the actual tension among stakeholders related to distrust and insufficient data collection, analysis and development of planning strategies, and at the same time, assess the genuine uncertainty on the condition of groundwater resources in the region.

Third, economic and social vulnerability assessments given different scenarios of water availability and different type of users or sectors, could also offer new perspectives and useful practical guidelines for research, and can open new opportunities to improve problem identification, solutions, communication, and feedback among stakeholders. Cost-benefit analysis could offer a practical tool to evaluate alternatives and planning strategies from an economic perspective that can be easily communicated and evaluated among different users and decision-makers.

As a subsequent result of the previous statements, there is also an urgent need to invest in short and long term planning policy development oriented to water allocation, physical efficiency use for urban and agricultural use, treatment, pricing schemes, present and future trends of water demand, sustainable options for different sectors and stakeholders, and of course, sustainable options to stop the degradation of water resources in the region.

Any new strategy or alternative for planning in the Laguna region must include an integrated research program that can identify mean priorities of research for short and long term perspectives; it should consider needs, perspectives and participation of all water users representatives; it should promote the development of a mechanism that helps identify the problems and develops a communication strategy that improves trust and effective feedback among stakeholders. Likewise, this mechanism should efficiently inform the society of what the main problems are, the risks, and the institutional responsibility towards the population and vice versa.

Finally, the way forward should not only consider the interrelations between stakeholders' interests and priorities and the condition of water resources in the region, but also the external forces. Economic depression, international trends towards sustainable energy and water use, water demand related to population growth, water pricing schemes and subsidies reconfiguration, decentralization of water management, virtual water management approaches, and water reuse, are just a few of the international trends towards water management. Comparing these trends and the potential sustainability demonstrated in this research, there seems to be a long road yet to be traveled before a sustainable approach is achieved, unless a dramatic collapse in the state of water resources forces decision-makers to make drastic changes to the actual economic development model based on intensive and extensive groundwater use.

From this perspective, there is a need to start constructing from scratch institutional leadership, trust, data reliability, positive feedback and communication, and look for long term sustainable results. Planning strategies that favor decentralization, and regionalization of the decision making process could help redesign the water institutional

capacity and prepare the area for critical situations. In the Laguna region there is a genuine need to rebuild the models of science development and applied research and to construct the necessary links and bridges between the scientific community, state institutions, and the society as a whole.

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PERSONAL INTERVIEWS

Federal Officials

Personal Interview. Jan 21, 2009

Personal Interview. Feb 2, 2009

State Officials

Personal Interview. Jan 23, 2009

Personal Interview. Jan 29, 2009

Personal Interview. Jan 28, 2009

Cities Officials

Personal Interview. Jan 21, 2009

Personal Interview. Jan 22, 2009

Personal Interview. Jan 26, 2009

Personal Interview. Jan 26, 2009

Personal Interview. Jan 27, 2009

Personal Interview. Feb 4, 2009

Private Industries

Personal Interview. Jan 24, 2009

Personal Interview. Feb 4, 2009

Irrigation Districts

Personal Interview. Jan 27, 2009

Personal Interview. Jan 26, 2009

Personal Interview. Feb 2, 2009

Private Farmers

Personal Interview. Feb 5, 2009

Personal Interview. Feb 3, 2009

Personal Interview. Feb 5, 2009

Academics

Personal Interview. Jan 21, 2009

Personal Interview. Jan 21, 2009

Personal Interview. Jan 24, 2009

Personal Interview. Jan 25, 2009

Personal Interview. Jan 28, 2009

Personal Interview. Jan 29, 2009

Personal Interview. Jan 26, 2009

Personal Interview. Feb 2, 2009

Personal Interview. Feb 4, 2009

Personal Interview. Feb 5, 2009

Personal Interview. Feb 5, 2009

APPENDIX A

A-1 QUESTIONNAIRE

1. PLANNING STRATEGY OPTIONS-PREFERENCES

Several planning strategies options may be available for meeting your regional water needs. We would like to know how much you prefer the following options.

Please circle your level of preference for each planning strategy that should be considered to improve the Laguna region water-scarce condition.

PREFERENCE

	Alternatives	Preference			
		None	Limited	Medium	High
1	Construct storage tanks that can be used during water scarcity or drought				
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping				
3	Drill new wells in new aquifers close to the region (for example, Jimulco).				
4	Elimination of subsidies to electricity use for agriculture and cattle production				
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.				
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).				
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).				
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).				
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.				
10	Potable treatment of Nazas river flow for domestic-urban use.				
11	Crop conversion (instead of forages, invest of new crops of less water consumption)				
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.				
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.				
14	Establish a limit to the agriculture frontier of 50,000 hec				
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.				

16	Forage imports that can substitute regional production				
17	Relocate the milk basin.				
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.				
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.				
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..				
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.				
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.				
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.				
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.				
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)				
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.				
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism)				
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter				
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).				
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.				
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.				
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.				
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).				
34	Construction of arsenic removal treatment plans for urban-domestic use.				
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.				

2. PLANNING STRATEGY OPTIONS-FEASIBILITY

We would like to know your views on the *feasibility* of several planning strategies to enhance regional water needs. In determining *feasibility*, you may consider any combination of economic, environmental, legal, political, technological, social or other factors.

Please circle how feasible you think the following planning strategies are for meeting your regional water-scarce condition.

FEASIBILITY

	Alternatives	**Feasibility**			
		None	Limited	Medium	High
1	Construct storage tanks that can be used during water scarcity or drought				
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping				
3	Drill new wells in new aquifers close to the region (for example, Jimulco).				
4	Elimination of subsidies to electricity use for agriculture and cattle production				
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.				
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, and urban-domestic).				
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).				
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).				
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.				
10	Potable treatment of Nazas river flow for domestic-urban use.				
11	Crop conversion (instead of forages, invest of new crops of less water consumption)				
12	Include environmental education, specifically hydrological resources, as a mandate in public schools.				
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.				
14	Establish a limit to the agriculture frontier of 50,000 hec				
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.				
16	Forage imports that can substitute regional production				
17	Relocate the milk basin.				
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.				
19	Develop new federal programs to improve irrigation infrastructure,				

	distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.				
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..				
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.				
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.				
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.				
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.				
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)				
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.				
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism)				
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter				
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).				
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.				
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.				
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.				
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).				
34	Construction of arsenic removal treatment plans for urban-domestic use.				
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.				

APPENDIX B

B-1 CATEGORIES OF ALTERNATIVES

Cat. 1	**Water pricing, subsidies redefinition, privatization**
4	Elimination of subsidies to electricity use for agriculture and cattle production
6	Apply differential subsidies based on extraction rates (crop type, land extension, irrigation techniques and water conservation, and combined subsidies for type of users and social priority (agriculture, cattle, industry, urban-domestic).
7	Redefinition of water price-cost of water (not only to the service). Differentiated tariffs based on volume (the larger the extraction, the higher the price) and type of use (urban, industry, agriculture).
18	Pay for environmental services incentives to stop the forest degradation upstream the basin.
32	Privatize surface and groundwater rights to private, foreign or national investment, for use, allocation and management.
35	Promote the development of cooperatives (For Example Jardin Torreon) for management and planning of their wells for urban, industry and agriculture use.

Cat. 2	**New water sources**
3	Drill new wells in new aquifers close to the region (for example, Jimulco).
10	Potable treatment of Nazas river flow for domestic-urban use.
21	Continue on with the *status quo* scenario (same extraction rate and patterns of actual water use) until the critical point is reached and will be necessary to take drastic measures.
33	Develop and implement the MEVA Plan (use of river flows from the State of Sinaloa and conduct them towards the Laguna region).

Cat. 3	**New regulations - enforcement**
9	Develop new legal instruments to enforce water utilities to increase their physical efficiency.
19	Develop new federal programs to improve irrigation infrastructure, distribution, conduction, and implementation of greenhouse-shadow homes programs and improved seeds.
20	Develop legal instruments that obligates the observance of the actual legal scheme related to limits to extraction, treatment, water rights, monitoring, meters, fines, overpumping, etc..
24	New laws that establish limits to plant high water consumptive ornamental-urban vegetation and utilize native vegetation.
28	Reduction of the national limit norm of arsenic concentration from 25 to 10 micrograms per liter
31	Investment on conservation and water savings campaigns directed to all sectors and all uses.

Cat. 4	**Changes and limits to agriculture production-priority to cities water supply**
1	Construct storage tanks that can be used during water scarcity or drought
11	Crop conversion (instead of forages, invest of new crops of less water consumption)
14	Establish a limit to the agriculture frontier of 50,000 hec
16	Forage imports that can substitute regional production
23	Construction of new dams or storage lagoons for drought periods for domestic water consumption.
30	Rescue of the best groundwater wells (best water quality-low arsenic concentrations) in declaration of public utility and reserve them for domestic use.
34	Construction of arsenic removal treatment plans for urban-domestic use.

Cat. 5	**Reduction of water pumping**
2	Comisión Nacional del Agua (CNA) should acquire water rights to stop overpumping
5	Donation of surface and groundwater rights by the large consumers to recharge the aquifer.
8	Redefinition of water rights. Proportional reduction of extraction rate based on recharge levels of the aquifer according to the CNA (pumping reduction down to 580 Mm3 annually).
22	Reduction to 800 Mm3 surface water use annually – or even less depending on storage variability- in the short term, with the purpose to reduce gradually water consumption in the long run supported and complemented with irrigation, crop use and distribution efficiency. The objective would be to increase the amount of surface water used to recharge the aquifer.
29	Donate a percentage of water rights to recharge the aquifer when selling of renting water rights (proportional to extraction rate).

Cat. 6	**Change model-decentralization of water management**
13	New public policies oriented to change regional agriculture and cattle vocation towards one that favors services and/or industry development.

17	Relocate the milk basin.
26	Considering the holistic approach of basin planning, create a new regional organism dependent of both states governments to plan, allocate and enforce regulations on water use, conservation, access and management of the region's water resources.
27	Decentralization of environmental-hydrologic public policies. Give the States and cities the jurisdiction-autonomy for planning, use and management of ground and surface waters, from an environmental sustainable point of view. (It would require constitutional changes-enforcement of federalism).

Cat. 7 Research-education

12	Include environmental education, specifically hydrological resources, as a mandate in public schools.
15	Promote the development of technical studies related to water reserves in the Acuifero Principal and soil hydrogeology, as a result of a consensus among users, researches and planner-managers.
25	Develop cost-benefit analysis of available alternatives (for example, crops diversification, treatment of Nazas river, installment of arsenic treatment plants, forage imports, irrigation improvement, and the rest hereby mentioned)

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Selected Publications:

Khedun, P. C., Sanchez, R, and J.R. Giardino, (2009). Climate Change and Transboundary Water Resources. Water Resources Impact 11(2):11-13.

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